



# Study on Baby Toy Design—From the Perspective of Audio-Visual Human Factors

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**Abstract.** Toys are partners that accompany children's growth and are indispensable that comfort children and promote their mental development. Since babies' physiology and psychology experience rapid development in babyhood (0–18 months). From the perspective of toy design and intellectual education, how to provide appropriate toys for stimulation according to perception and motor development is very important. However, it can be seen from the current toy design practice that most relevant design studies are only for school-age children; there are few studies on baby toy design. The objectives of this study are to ensure that baby toy design is based on academic and theoretical basis and make the design more rigorous to have more positive value to the physical and mental development of babies. Therefore, this study takes intelligent toy design as the viewpoint to conduct study on homologous visual and auditory human factors in babyhood and provide relevant data on human factor to achieve useful and effective design. Since the babies in this study are not yet mature in mind and body, there are a lot of limitations compared with general study objects. Therefore, this study adopts document analysis and expert interviews to study on human factors for baby toy design. The results obtained the following data on babyhood: (1) physical development process at different stages; (2) features of visual ability development at different stages; (3) features of auditory ability development at different stages; and (4) policies and suggestions for toy design for different stages.

**Keywords:** Educational toys · Toy design · Baby human factors

## 1 Introduction

'Do not let children lose at the starting line of life' expressed most parents' expectation for their children. Therefore, they would like to grasp any opportunity that may make children grow, even 'playing'. They hope that playing 'toys' can allow their children to explore the world and develop their intelligence. 'Toys' are important partners that accompany children's growth and are indispensables that comfort children and promote their sensory and mental development. The so-called 'educational toys', which emphasize that they can enlighten intelligence, stimulate brain development and develop intelligence, have been advertised in recent years. In fact, the selection of toys is highly correlated to development stages of babies and young children. Appropriate toys selected according to the development needs at different stages can not only inspire babies' intelligence, train visual, auditory, tactile and other sensory functions and stimulate creativity, but also help physical growth and intellectual education. On the contrary, toys not in compliance with children's stages of physical and mental development are not beneficial to their development and may do harm to them.

In babyhood and childhood, the physical and psychological developments of babies and young children experience rapid changes. Although their sensation and perception systems are not mature, there is significant progress in their development every month (Shaffer and Kipp 2013). From the perspective of toy design and intellectual education, since babies develop rapidly in babyhood, it is very important to learn about their perception and motor development and provide appropriate toys for stimulation in correct development months. For example, 1-month-old babies are at an early stage of visual development when their visual angle is only  $15^\circ$ , they are only interested in black and white pictures, they can only slightly raise their heads, and their heads move with their eyes. Only upon learning about this can designers design effectively according to such human factors and achieve the purpose of educational toys. However, it can be seen from baby toy design practice that most relevant design studies are only for school-age children; there are few studies on human factors for baby toy design. According to the Theory of Multiple Intelligences and Physical and Psychological Development in Babyhood of Gardner (2011), a professor at Harvard University and a developmental psychologist and education scientist, the intellectual education on babies at this stage mainly focuses on visual and auditory aspects, such as spatial vision, language, body kinesthetic, natural observation and music; since babies and young children are not yet fully developed, advanced intelligence aspects, however, are relatively uncorrelated. To conclude, the objectives of this study are to ensure that visual and auditory design is based on academic and theoretical basis and make toy design more rigorous to have more positive value to the physical and mental development of babies and young children. Therefore, this study attempts to obtain the related human factors in babyhood from the perspective of intelligent toy design and that human factors can be effectively grasped during corresponding toy design, so as to achieve useful and effective design. The following questions are studied: (1) What is the process of physical development at different stages of babyhood? (2) What are the characteristics of visual development at different stages of babyhood? (3) What are the

characteristics of auditory development at different stages? (4) Any suggestions for toy design based on physical and mental development at different stages?

## 2 Literature Review

### 2.1 Overview of Stages of Human Development

The course of human life begins at the moment of conception and ends with death. In this process, there are changes in quality and quantity at physical, psychological and social levels. Such changes are not temporary or incidental, but a directional and structural continued progress to maturity; and such changes are interrelated (Santrock 2006). Scholars Shaffer and Kipp (2013) further divided each stage into six stages according to developmental changes as shown in Table 1. The babyhood from birth to 18 months is a stage with the fastest rate of physical development. Babies get to know the concept of things in the world to establish schema.

**Table 1.** Stages of human development

Development stage	Age range
Prenatal stage	From conception to birth
Babyhood	From birth to 18 months
Toddler period (toddlerhood)	18 months - 3 years old
Preschool period	3–5 years old
School period (middle childhood)	5 - around 12 years old (before adolescence)
Adolescence	12–20 years old (the ending is defined as the time when individuals start working and can live independently)
Adulthood	20–40 years old
Middle-age period	40–65 years old
Senile period	Above 65 years old

Data source: Shaffer and Kipp (2013)

### 2.2 Physical, Visual and Auditory Development in Babyhood

The physical development in babyhood mainly includes two aspects: (1) physical development - development of all body parts; and (2) motor development - brought about with physical development (Shaffer and Kipp 2013; Skelton 1997; Stoppard 2007). Newborns have basic sensory functions upon birth. They can perceive surrounding visual, auditory and olfactory stimulations and can response to such stimulations. However, the relevant physical and perceptual abilities in ‘babyhood’ may gradually get matured with the accumulation of experiences in physical development and learning process. Perception is the meaningful sense formed from the physical and sensory information integrated by the brain. The development of perception, together with

physical development, memory and experiences, is closely correlated to individuals' growth (Shaffer and Kipp 2013).

The cornea and crystalline lens in eyes are of transparent structure, thus light can be focused on the retina via the light-gathering effects of the two structures, stimulating photoreceptor cells to produce vision. Vision is the sense by which individuals distinguish the Light and shade, color, shape and other characteristics of external objects (Eysenck and Keane 2015). Babies' visual functions begin to promote visual development with visual exploration in the process of growth and mechanisms that rely on experience. Therefore, mechanisms of innate abilities and experiences will jointly promote the development of babies' visual system. The auditory sense is one of the most primitive sensory perception of humans and can be divided into three forms: language, music and noise (Shaffer and Kipp 2013). The auditory sense has developed to a certain extent in the fetal period. Especially at the end of pregnancy, the fetus is already sensitive to the sound of its mother's voice and some external sounds and even feels that the sounds heard in its mother's womb have a certain stabilizing power. Babies have some degree of auditory ability, including responding to sounds and trying to find the sound source (Shaffer and Kipp 2013). Therefore, when babies cry or are unhappy, they will gradually calm down when their mothers play some music often heard during pregnancy. See Table 2 for relevant concepts of sounds and music. Physical development and perception are necessary conditions influencing motor development. Therefore, it is important to learn about babies' perception and motor movement and providing appropriate toys for stimulation.

**Table 2.** List of relevant concepts of sounds and music

Perceptual element		Physical element	Description
Sounds	Volume	Amplitude size (dB)	The higher the volume, the greater the amplitude; the lower the volume, the smaller the amplitude
	Pitch	Vibration frequency (Hz)	The higher the frequency, the higher the pitch; the lower the frequency, the lower the pitch
Music	Timbre	Waveform of sound	An important feature for identifying the timbre of an instrument. The sources of different timbres can be distinguished, i.e. from different instruments or people
	Melody	A structure formed by sounds	Refers to a sequence of sounds with specific high and low and rhythm relations
	Rhythm	Frequency of sound	A fast or slow beat at a certain speed

Source: sorted in this study

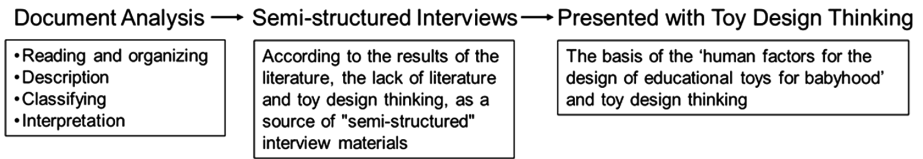
### 2.3 Educational Toys

Such toys promote, by edutainment, players' sensory exploration and cognition of the world, including inspiring the development of language, music, logical/mathematical,

visual/spatial, bodily/kinesthetic, curiosity, imagination and intellectual achievement (Frost et al. 2001; Ogata 2004). Besides, such toys also bring about joy, companionship and autonomy and improve memory, aesthetic ability and concentration (Goldstein and Goldstein 1994), thus are recognized by most educators.

### 3 Method

The objective of this study is to obtain the human factors for the design of educational toys for babyhood to make such design suitable for 0–18-month-old babies and ensure that the design of receive audio-visual stimuli is based on academic and theoretical basis. Since the objects in this study are not yet mature in mind and body, there are a lot of limitations compared with general study objects. Therefore, first of all, this study obtains the ‘physical and psychological development progress for babies in different months’ by document analysis and by widely collecting, reading and concluding from medicine, physiology, cognitive science and anthropology and other fields. Next, the deficiencies in the review results and toy design thinking are taken as the material source of ‘semi-structured’ interviews (expert interviews), which are carried out with four experts respectively, with interview results sorted out; finally, the ‘policies and suggestions for toy design’ are proposed on the basis of the ‘human factors for the design of educational toys for babyhood’ and toy design thinking as shown in Fig. 1 (Table 3).



**Fig. 1.** The research method used

**Table 3.** List of experts

No.	Background	Area of expertise
1	Doctor of Physiology	Neurophysiology and young children development, cognitive neuroscience and sensory integration
2	Doctor of Musical Arts	Music and fetal education and effects of music on young children development
3	Head of music rhythm institution for babies and young children	Music potential and rhythm, and early childhood music and rhythm
4	Doctor of Music	Music and sound therapy, sound beam assisting young children development, and regulation of young children’s emotion by music

## 4 Results

Since relevant contents are complex, we obtained the following results and suggestions by widely collecting, reading and concluding more than 100 pieces of relevant literature from medicine, physiology, cognitive science and anthropology and by expert interviews.

### 4.1 Physical Development Process for Babies in 0–18 Months

This paper sorts out the Physical Development Process for Babies in 0–18 Months (Table 4) according to babies' physical and psychological development. The physical development of most babies is regular and can be used as the reference basis for babyhood toy development. However, every baby has a different constitution, thus there are still individual differences in physical development.

**Table 4.** Physical development process for babies in 0–18 months

Time	Motor development characteristics
Birth	Babies gradually adapt to the strange world via sleeping; crying is the only way to express their emotion; heads can rotate slightly when supported; they can move and lift their hands and feet; they can clench their palms when someone touches the palm
1 month	The head moves with eyes; babies can slightly raise their head; when they lie down, they can lift the chin; they will unconsciously suck fingers; reflex actions of the palm are reduced, but the palms are still clenched; when they are awake, they can play alone for about 30 min
2 months	2-month-old babies can keep their head straight when they are held by someone; their upper and lower limbs can stretch and kick; they will not go to sleep immediately after drinking milk and may play for about 30 min; when they lie flat on the stomach, they can briefly raise the head for 45°
3 months	Reflex actions of the palm completely disappear; babies often stare at their hands; when they lie flat on the stomach, they can raise the head for 45°; when they are held and lifted, they can kick alternately
4 months	They become interested in their hands and often suck fingers; they can control their hands and feet and can simply turn over; they can sit when assisted by supports; when they lie flat on the stomach, they can raise the head for 45–90° and like to look around; they can catch toys, suck toys with mouth and shake toys; they can babble and smile cordially at their mothers; they can see distant things, stare at people, reach for distant objects and track moving objects; they may suck fingers and make sounds to amuse themselves
5 months	Babies lick everything with their mouth to learn about the world; they can catch things without using their thumbs; their muscles are strengthened and they can fully control their neck muscles; they can lift the chest; their feet can support their weight and can turn over; they know the existence of toes and put fist into mouth, indicating that they can use eyes and hands simultaneously; they can distinguish acquaintances and strangers and begin to be afraid of strangers and clingy

(continued)

**Table 4.** (continued)

Time	Motor development characteristics
6 months	Babies can turn over by themselves; they can sit on chairs with a back; they can catch hanging objects and can pass objects from one hand to another hand; they can point the corresponding position with thumb or other fingers and can pick up things or grasp with both hands; they know that things in hands should be thrown away before getting a new thing; the muscles of both arms are strong enough to support the body; they can reach out for hugging and may put things into mouth due to the tickle of gingiva
7 months	Babies can sit by themselves for several minutes and can support with hands, knock with toys and help themselves to finger food
8 months	Babies begin to crawl and can use the thumb to grab something and pick up small things with the thumb and the index finger; they can tear paper, hold things and crawl (pull the body and feet with hands); they can move the body to get close to things they want; they may try to stand when someone holds their arms
9 months	Babies can stand with the help of something and can sit on their own for 10 min and will not fall down even they shake back and forth; they can roll, want to get up, and can push, pull, drag or hold objects
10 months	When babies are sitting, they can be free to move and rotate the body with hands and knees and can stand up by themselves and begin to walk along tables and chairs; they can control their index fingers to get things and put them down; they can eat the food in their hands and like to throw things
11 months	Babies can crawl with the help of hands and feet and may try to walk a few steps; they can give things to others and put them into containers
12 months	Babies can stand by themselves and try to walk a few steps; they can catch and put down the ball and may try to take two objects with one hand
13–18 months	Babies can climb stairs, stoop to pick something up and scratch with a pen; they like to throw things and walk independently and can run awkwardly; They can stoop and bend their knees and like to push and pull, throw balls, turn pages and scribe

Source: sorted in this study

## 4.2 Arguments for the Characteristics of Visual Development at Different Stages of Babyhood

Babies' visual functions begin to promote visual development with visual exploration in the process of growth and mechanisms that rely on experience. Therefore, mechanisms of innate abilities and experiences will jointly promote the development of babies' visual system. Since various visual abilities in babyhood have different development in different growing periods, in order to help to understand such development and further apply such development in the development and design of toys, we further conclude and sort out the 'visual ability processes in babyhood' in this study. See Table 5.

**Table 5.** Visual ability processes in babyhood

Time	Visual ability development
0 month	The optimum staring distance is 20 cm. Babies cannot clearly see too close or too far objects and can respond to 'light'. When the light is too bright and strong, babies may not adapt to this and may turn the head to the other side. Their visual acuity is 20/600 and their vision is about 0.05–0.025; they like faces and objects with clear and simple contour. Visual angle: 15° from the midline on the left and right respectively
1 month	Babies can see objects 20–30 cm from their faces. Visual angle: 30° from the midline on the left and right respectively. The fixation time can be up to 3–5 s
2 months	Color discrimination ability: babies can distinguish different colors (such as red, yellow and orange), but they prefer white and black (neutrals); the fixation time in 2–3 months can be up to 7–10 min; their eyeballs can accurately chase objects and can chase objects horizontally and vertically, but cannot chase the object beyond the midline of the body)
3 months	Red is the most attractive color for babies; they can see objects 4–7 m away, chase objects to the midline of the body and actively find visual stimuli. Since they can see a distance of a room, they begin to identify the environment
4 months	Their vision is about 0.1 and can see the difference between near and far; their stereoscopic sense also develops rapidly at this time; 4–8-month-old babies are interested in things in warm colors (red, yellow and orange) and do not like cool colors (such as blue and green) and pale colors (such as gray and brown); they may show a preference for a certain color;
5 months	Visual angle: 45° from the midline on the left and right respectively
6 months	Their vision is 0.5; they can distinguish 3D patterns and establish stereoscopic vision; visual acuity: 20/100;
9 months	They can see things as near as 2–3 cm;
12–18 months	13-month-old babies can recognize and correctly point out red, green, blue and yellow

Source: sorted in this study

Since the wave length of soft yellow-green light is long, eyes are highly sensitive to yellow-green light and are not easy to be fatigue. In terms of colors, in the first 3 months after birth, babies can only recognize white and black; 3–4-month-old babies can recognize red, green and blue. Later, with the accumulation of life experiences, babies may have different color preferences in different periods. This cannot be judged according to physiological factors. With regard to shapes, 3–4-month-old babies can only recognize the basic contour of objects. Later, they will begin to recognize details and are especially absorbed in moving objects.

### 4.3 Arguments for the Characteristics of Visual Development at Different Stages of Babyhood

Normal newborns have auditory sense immediately after birth (Shaffer and Kipp 2013) and can 'stare at the person who speaks' (Rheingold and Adams 1980; Rosenthal 1982); and are most focused on high frequency sound (Ecklund-Flores and Turkewitz 1996).



Thus, babies can quickly learn to recognize the words that they often hear. 4–5-month-old babies can turn their heads when someone call their names but have no response to other names (Mandel et al. 1995); when they are 7 months old, they can generalize the patterns learned from language to other sounds, such as pitch, the timbre of an instrument and the sound of an animal (Marcus et al. 2007). Therefore, from the perspective of cognitive learning, repeating simple nursery rhymes, singing sweet songs and saying loving words will be highly favorable to the development of auditory sense, emotion and movement. On the contrary, excessively loud, sharp, irritating or unpleasant sounds may scare babies. Their brain and auditory system will repel these sounds, which is extremely detrimental to brain development (Karmiloff and Karmiloff-Smith 2004; Stoppard 2007).

It can be concluded that babies' auditory sense starts in the fetal period. In the process of auditory development, babies can recognize multiple sounds in surrounding environment and master human languages. Babies' auditory susceptibility has significant individual difference. Some have higher susceptibility and that of others is lower, but such individual difference is not unchanging. In fact, babies' auditory sense keeps developing under the influence of living conditions and education. Lastly, in order to help to further understand auditory development processes and apply them in toy development and design. We further conclude and sort out auditory development processes in this study. See Table 6.

**Table 6.** Auditory development processes in babyhood

Time	Auditory ability development
0 month	Normal newborns have auditory sense immediately after birth and can 'stare at the person who speaks'; they can recognize their mothers' voices, for which they show obvious preference
1 month	Babies can distinguish 200 Hz and 500 Hz pure tones; when they are sleeping, if they suddenly hear some sound, they may open their eyes and cry
2 months	When babies are sleeping, if there are noises, they may open their eyes but they will not cry; they can distinguish flutes and bells
3 months	They begin to identify and distinguish sounds and can preliminarily distinguish 'pitches'; they may be uneasy when hearing a quarrel and may be happy when hearing music and like high frequency sounds
4 months	Babies can combine auditory sense and visual sense and can turn their heads towards the direction of sounds
5 months	The auditory differential threshold within 200–2000 Hz among in 5–8-month-old babies doubles that among adults; the auditory differential threshold within 4000–8000 Hz is the same as that among adults; in case of any sudden sound, babies may rush to hug the caregiver (such as mothers) and may turn their heads when hearing their names
6 months	Babies can hear external sounds below 1000 Hz and respond to mothers' voice
7 months	Babies can distinguish different sounds in a language and can extract patterns from voices
8 months	Babies may actively make some sounds and imitate others' words that they hear

(continued)

**Table 6.** (continued)

Time	Auditory ability development
9 months	Babies can distinguish whether sounds are meaningful, for example, someone calls their names
10 months	Babies can imitate to call father and mother
12–18 months	Babies can rapidly and directly search for sound sources and can distinguish finer sound of different phonetic symbols, such as barking and honking

Source: sorted in this study

If babies are exposed to music early, the music elements in music tunes that vary in height, speed, and strength can better inspire the development of children's sensory perception and music ability (Karmiloff and Karmiloff-Smith 2004). Babies' musical ability first is that their auditory sense hears music and generates feelings. Then such delighted feelings drive them to find 'sounds' and make 'sounds' by themselves to experience the relationship between sounds and people, things, objects, time and space. Thus, such interests increase with time, leading to the music ability cultivation and skill learning. For this point, Moog (1976a, b) pointed out on the basis of a study on babies cognitive abilities: 0–4 months: babies are sensitive and feel safe to high frequency music and noise, thus women's and children's voices can make babies calm down; after 4 months: babies like 'delighted music' and 'beautiful voices': after 6 months: strong sounds cannot make babies physically move with music, but 'delighted music' and 'beautiful voices' can; 18 months: 10% of babies can physically move with music rhythm (Moog 1976a, b). Besides, relevant studies also proved that when babies are 2 months old, they can lie still and listen to music; when they are 2–3 months old, they can preliminarily distinguish 'pitches'; when they are 3–3.5 months old, they can distinguish 'timbres'; 5–6-month fetuses have music perception; when they are 6–7 months old, they can distinguish simple 'pitches'.

Sinor (1980), an American scholar of music education proposed, according to the 'cognitive-developmental theory' of Jean Piaget, a developmental psychologist, the 'musical development of children', which shows that 0–1-year-old babies begin to develop the dynamic and timbre of perception, and listening and moving abilities of response. The musical activities before 1 year old emphasize tunes and intonation related to music, rather than linguistic speech on the rhythm of music. Babies can also distinguish different rhythms.

It can be concluded that music does soothe emotions. The frequency of music is very important in soothing music. Low frequency is for comfort. However, this does not mean always playing low frequency music to fetuses. The music should have some changes, such as the changes in tone and cadence. A cradle song is soothing, but it should be accompanied by the hug from adults. A cradle song should be slow with stable pitch, such as the stability of Baroque music, the rhythm of which is close to heart rate. The mind-inspiring music should be diversified, not too long, highly comparative and repetitive. Music for mental development should have design lesson plans and music with meaningful guidance. Babies' audition is very sensitive, thus the volume of toys with sound should be below 50 dB.

#### 4.4 Suggestions for Design of Acousto-Optic Toys Based on Physical Development of Babies and Young Children

For visual sense, although light can easily attract their attention, hurts can be easily caused. Therefore, light should be carefully designed. Please use indirect light. Among lights, blue light is terrible, thus do not apply it. It is suggested not to develop the visual sense of 0–3-month-old babies. Hanging toys can be added to babies above 4 months. Toys may not be dynamic and in black, white and warm colors with high saturation, such as red, yellow and orange. For babies above 5 months, toys may be dynamic to allow babies and young children to practice eyeball tracking.

For auditory sense, the sounds of music should be from real instruments with stable melody and range, for example, there are a total of seven tones, the range of which should not be too wide. The melody should be within one range without large fluctuations. The speed of music should be one beat in one second, that is, sixty beats in one minute. Generally speaking, such speed is in line with heart rate. For voice, mothers' voices can be used (for example, when clicking the pictures of cars, "car" will be said) to enhance babies cognition. The adding to motherese to the sound feature of products can increase babies' preference. Such motherese can also be interspersed in different paragraphs by playing motherese first to lead babies stare on left and right sides to promote their visual development. Since sounds have the synesthesia of colors and visual perception, the match of sounds and colors can be used to train the synesthesia of babies and young children. Meanwhile, the match of visual features with sounds, such as the match of a dog shape with barking, should be taken into account when designing toys for babies and young children above 12 months.

Finally, we propose the following summaries and suggestions for different stages:

- (1) 0–3 months: this stage emphasizes the soothing sound rather than the soothing light/visual objects.  
For 0–3-month-old babies, since their visual sense has not been fully developed, the staring distance increases from 20 cm to 7 m, and the staring can last as long as 10 min, the stimulation development for this stage should be based on sound, rather than visual ability.
- (2) Above 4 months: addition of object space concept  
Babies above 4 months begin to develop synesthesia and 3D concept. At this stage, the combination of sounds and objects can be used to train babies' sense of space.
- (3) 5–12 months: learning of music and training of perception  
Babies and young children above 5 months can identify timbres, pitches, tones, melodies and simple tunes in music. Therefore, it is suggested to train babies' music perception, including different timbres, rhythms and melodies.
- (4) Above 12 months: emphasis of the interaction between sound and movement  
Babies and young children above 12 months begin to have body movements, thus different music or sounds can be used to guide the learning of body movements of babies and young children at this stage.

## 5 Conclusions and Suggestions

This study enriched the relevant human factors for baby toy design by different academic literature review and expert interviews and proposed design suggestions for different stages. The results can be applied to the development of educational toys for babies. Therefore, it can be concluded from this study that the design of the educational toys for 0–18-month-old babies should be focus on the development of sound senses. If visual lights are used, please use indirect lighting; blue light is prohibited. Mothers' voices are important for children. However, the design of few products on the market has applied mothers' voices. It is suggested to apply such voices during design.

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