

# Children and time

Sylvie Droit-Volet on what we can learn about the biological and cognitive basis of time from the way children judge duration

**During the decades following Piaget's work, it was believed that correct judgements of durations require sophisticated reasoning abilities that emerge at about eight years of age. However, recent studies have shown that infants and young children are able to discriminate different durations, despite their limited conceptual capacities. This suggests that a basic internal clock system is functional at an early age.**

**The main distortions in time judgements in children are shown to be due to attention/executive functions that are not sufficiently developed to allow the correct processing of time whatever the context.**

The most brilliant minds of philosophy and physics have long pondered the question 'What is time?'. Famous disputes, such as that between Newton and Leibnitz on the absolute or relative nature of time, continue to echo across the centuries. What is the true nature of time, and does it have any genuine existence?

Psychologists have largely left such debate to one side, and focused on trying to study the psychological reality of time through the feelings and behaviours of humans faced with the passage of time. As Bergson (1968) says, 'time is purely and simply an item of data relating to our experience... and we want to hold onto that experience'.

What psychologists have discovered is that there is no simple, undifferentiated type of time knowledge. Instead, multiple forms of time emerge at different stages along the ontogenetic scale as a function of the development of underlying cognitive processes. We will focus here on the development of the ability to judge event durations or intervals between events.

## Pioneering studies

At the beginning of the last century, Swiss psychologist Jean Piaget greatly influenced research on time in children. In his theory of intellectual development, he described how young children explore their environment through their senses and actions. The primitive understanding of the physical world, therefore, appears to be grounded in sensorimotor knowledge. It is only at the transitional

period of seven to eight years of age, when children reach the concrete operational stage, that they think logically and manipulate the symbolic representations that enable them to solve complex problems.

According to Piaget, young children are thus unable to evaluate time accurately before they acquire the capability to reason logically about it. For example, children estimate durations as a function of the quantity of work accomplished or effort produced. Piaget found that children who were asked to place lead disks or wooden disks in a box for a given period thought that the task involving the lead weights took longer than the one in which wood was used, because it required greater effort. This finding has been replicated in numerous studies showing that young children evaluate durations on the basis of their non-temporal content: for example, the presentation duration of a light or a moving car is judged longer when the brightness of the light or speed of the car increases (Arlin, 1989). Young children's time judgements are therefore context-dependent and closely bound up with the situation within which time is experienced.

The fact that children distort time in certain conditions does not mean that they do not possess a basic time discrimination ability. The task is to determine the conditions in which children's time judgements are or are not accurate, and why.

However, children's ability to estimate time accurately emerges earlier than the pioneering psychologists thought. As we will discover, infants with only limited conceptual capacities are able to discriminate different durations.

## Explicit time processing

The problem is that young children are able to estimate time correctly only if they are forced to pay attention to it, to experience it on the basis of duration required to perform their actions, or through frustration when their needs are not immediately satisfied. When these

### questions

Are children able to estimate time?  
Is the internal clock operational at an early age?

### resources

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conditions do not apply, time does not appear to be relevant to them in the majority of everyday situations. This explains why the verbal instructions given by adults (e.g. 'please wait', 'not yet', 'in a few minutes') play such an important role in establishing temporal behaviour in young children.

However, in cases where timing is based on verbal rules and children's awareness, we talk about a specific type of time processing – the explicit processing of time. Explicit time judgements are primarily involved in the processing of longer durations when we focus on the continuous flow of time, in judgements of new and unpredictable events, and when there is no opportunity to repeatedly experience the duration associated with a particular event. Humans frequently make explicit judgements of time in real-life

situations, and the inaccuracy and variance observed in their temporal judgements may be the rule rather than the exception. Given this and the typical use of verbal instructions and small numbers of trials in most laboratory experiments examining time-related issues in children, it is little wonder that young children perform poorly when required to make explicit time judgements.

However, at the age of seven years, their time judgements improve because they acquire a symbolic representation of time. They represent time as something absolute that flows uniformly, and this enables them to measure the duration of events independently of their specific characteristics. This representation of time, which is close to Newton's conceptualisation, allows children to think about time *per se*, and resist their tendency

to distort it. Recently, in our laboratory, we showed that the increase in the accuracy in time judgements goes hand in hand with a growing conscious awareness of subjective time distortions (Lamotte et al., 2012). At the age of 10 years, children also begin to use verbal counting strategies, in the same way as adults, in order to ensure the accuracy of their time judgements. At eight years, although they are also capable of counting time, they do not spontaneously think of doing so unless instructed to by an adult. At five years of age, in contrast, they are unable to correctly count time, whatever the circumstances.

### A primitive time sense

Unlike explicit time processing, the implicit processing of time relates mainly to the processing of short durations (< 1s) associated with motor timing, temporal conditioning or implicit temporal learning involving multiple trials, as has been used in experiments conducted in animals. In these conditions, both infants and children as young as three years appear to be able to perform accurate timing.

There is now ample evidence that infants' reactions can be conditioned to temporal intervals that do not correspond to any biological rhythm. For example, Brackbill and Fitzgerald (1972) showed that the pupillary reflex can be conditioned to time in infants aged one month. After being conditioned to light changes occurring at a constant interval of 20 seconds, the infants' pupils continued to contract every 20 seconds even in probe trials in which there were no changes of light. This clearly demonstrates that infants can perceive the passage of time during a temporal interval.

Using an operant conditioning procedure, researchers have also shown that two- to five-year-old children are able to space their



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responses by a given temporal interval in order to make some slides appear on a screen (Droit et al., 1990; Pouthas, 1985). Erratic patterns of responses in this set-up are due to the fact that young children find it difficult to prevent themselves from responding, rather than a specific timing deficit. Indeed, their performances in such tasks improve considerably when they perform motor activities during the waiting period.

Recently, Provasi et al. (2010) also succeeded in adapting a temporal discrimination task, the temporal bisection task currently employed in animals, for use in four-month-old infants. During a training phase, the infants were presented with two sounds, one 'short' (0.5s) and one 'long' (1.5s). They were then trained to look to the left after the 'short' and to the right after the 'long' duration (the order was counterbalanced), with a correct response causing a picture to be displayed on the side toward which the infant had looked. During the test phase, the infants were presented with the 'short' and 'long' sounds, but also sounds of intermediate duration (750, 1000, 1250ms). In these conditions, the proportion of 'long' responses from the infants increased with the length of the stimulus duration. This demonstrates that infants are able to discriminate changes in stimulus duration.

In addition, the fundamental scalar properties of timing, observed in both animals and human adults, have been found in the temporal bisection task with children of different ages ranging from three to eight years (Droit-Volet & Wearden, 2001). The first scalar property is *mean accuracy*, the requirement that time estimates are on average equal to real time. The second property is the *scalar property of variance*, the requirement that the standard deviation of time estimates varies linearly with the mean, a form of Weber's law (Wearden & Lejeune, 2008). Weber's law therefore holds in children's

time discrimination behaviours at different levels of the ontogenetic scale. Overall, these results suggest that there is a primitive sense of time that is shared by most species of animal.

### The basic mechanism of time

The exact type of mechanism involved in time discrimination is a current topic of debate. According to the best-known theory of psychological time, referred to as scalar expectancy theory (Gibbon, 1977; Gibbon et al., 1984), the raw material for the representation of time comes from an internal clock composed of a pacemaker-accumulator system. The pacemaker continuously emits pulses. At the onset of the stimulus to be timed, an attentional switch connecting the pacemaker to the accumulator closes and allows the pulses emitted by the pacemaker to flow into the accumulator. At stimulus offset, the switch reopens and stops the flow of pulses. The time estimate therefore depends on the number of pulses accumulated during the elapsed period:

The more pulses that are accumulated, the longer the duration is judged to be.

Many researchers in the neuroscientific field have tried to identify the neural substrates of this type of internal clock system.

However, they have so far been unable to identify a simple neural mechanism dedicated to the processing of time. Brain activations during temporal tasks are always dependent on the type and complexity of the task used. This has led Eagleman (2005) to conclude that 'the neural basis of time perception remains shrouded in mystery'.

However, current hypotheses consider that two main brain structures play a critical role in time perception: (1) the prefrontal cortex and (2) the striatum, or more precisely the caudate and putamen of the dorsal striatum via dopaminergic

modulations. In the striatal beat frequency model, Matell and Meck (2000) suggested that the neural inputs that constitute the time code arise from the oscillatory activity of large areas of the cortex. At the onset and the offset of the stimulus to be timed, the oscillatory activity of a subset of these cortical neurons is synchronised. The striatal spiny neurons that receive inputs from the cortex detect patterns of oscillatory firing (or beats) that match other patterns stored in memory. They then fire to indicate the offset of the stimulus. In other words, the striatum of the basal ganglia plays a central role in timing by reading the temporal code provided by oscillating neurons in the cortex.

How does this relate to children? Well, the prefrontal cortex and striatum mature at totally different rates. Subcortical structures that are phylogenetically older mature earlier. The structures that constitute the basal ganglia (e.g. caudate, putamen, substantia nigra) are effectively the first of the telencephalic structures to begin to myelinate. In contrast, the prefrontal cortex matures slowly, until the end of adolescence. Such underlying processes may partly explain similarities and differences in temporal performance as children develop.

The basal ganglia influence time perception via the dopaminergic (DA) system. Many pharmacological studies have shown that the administration of a drug that increases the level of DA in the brain (metamphetamine, cocaine) speeds up subjective time (see Ogden and Montgomery's article in this issue), thus producing a lengthening of the stimulus duration to be encoded. In response to negative emotions such as fear, the detection of a danger by the organism also results in a release of DA in the brain. Numerous studies (e.g. Droit-Volet et al., 2011) on the perception of time have shown that time is overestimated in response to threatening (e.g. angry faces, threatening events) compared to neutral stimuli. More interestingly here, the lengthening effect produced by highly

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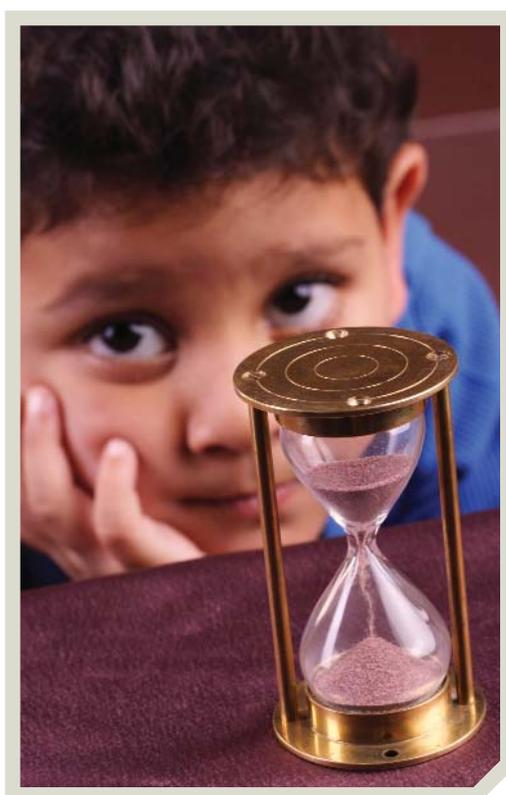
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arousing emotional stimuli (angry faces) has been observed in children of different ages (from three to eight years) with no developmental effect (Droit-Volet & Gil, 2009). Children have also been shown to overestimate time in the presence of periodic events (repetitive clicks, flickers) that have been shown to speed up the internal clock, just as adults do (e.g. Droit-Volet & Wearden, 2002). In sum, these results suggest that the time mechanism involving the striatum, and the way it is modulated by the DA system, is functional at an early age.

### A noisier perception

Despite phylogenetic and ontogenetic similarities in the perception of time, there are also developmental changes. Using a habituation paradigm, Brannon and her collaborators (2007) showed that six-month-old infants were able to discriminate two durations that differed by a ratio of 1:2 (1.5s vs. 3s) but not of 2:3 (1s vs. 1.5s, 2s vs. 3s). Our studies conducted in older children using a temporal bisection task with a wide variety of durations (both shorter and longer than one second) have also described an age-related improvement in temporal discrimination between five and eight years (Droit-Volet, 2011). Indeed, the five-year-olds succeeded in discriminating durations that differed by a ratio of 1:2 or 1:4, but not by a smaller ratio (3:3.6), while the older children performed better in the latter condition. In fact, all the bisection studies conducted so far have revealed that children's sensitivity to time improves with age to become similar to those observed in adults by eight years of age, although some age differences persist in particular conditions, such as with very long durations.

The reduced sensitivity to time in children is explained first and foremost in terms of the more limited cognitive resources available to young children, due to the development of attention and executive functions related to the slow maturation of the prefrontal cortex. This leads to a 'noisier perception' of time, partly due to the difficulties experienced by children in keeping their attention focused on the passage of time. Using a series of neuropsychological tests designed to assess cognitive abilities in children, Zelanti and Droit-Volet (2011) revealed a significant correlation between temporal sensitivity (Weber ratio) and the attention/concentration score on the Children's Memory Scale (CMS). The



higher the children's attention/concentration score, the better their sensitivity to time. This explains why time estimation is often impaired in children with attention deficit hyperactivity disorder (ADHD).

The accurate processing of time does indeed involve all the dimensions of attention: oriented attention, divided attention, selective attention and sustained attention. Attention must be prepared in order to capture the beginning of the forthcoming stimulus at the right time, even though this involves the risk of losing some temporal units. Droit-Volet (2003) showed that a signal warning children of the onset of visual stimuli to be timed reduced the variability in their time discrimination. Furthermore, if individuals are to be able to process time correctly, they must possess a high level of attentional resources. A number of studies (e.g. Coull et al., 2004) have demonstrated that time is judged shorter in a dual task, when attention is divided between a temporal and a non-temporal task, than in a single temporal task. Using dual-task paradigms, it has been shown that five-year-olds, who possess a limited pool of attentional resources, underestimate time more than older children (Gautier & Droit-Volet, 2002a). The development of selective attention capacities also allows children to resist attentional distractors and focus their attention on the processing of time. Consequently, the use of

attentional distractors in a temporal bisection task has been found to impair the time discrimination of five-year-old children more than that of eight-year-old children (Gautier & Droit-Volet, 2002b). In sum, children's distractibility and their deficit in inhibitory control prevent them from correctly apprehending the continuous flow of time.

The attentional control deficit exhibited by young children also explains why they are more subject than adults to temporal illusions. Two temporal illusions have been widely investigated in time psychology: (1) the visual-auditory illusion, where the duration of an auditory signal is judged longer than that of a visual signal presented for the same period of time, and (2) the empty-filled illusion, where an empty duration (temporal interval between two short signals) is judged to be shorter than a filled duration (duration of a signal).

Developmental studies (e.g. Droit-Volet et al., 2004) have shown that the visual-auditory illusion is greater in five-year-olds than in eight-year-olds or adults. It is an established fact that more attention is required for the temporal processing of visual than of auditory signals, the former requiring young children to continuously keep their attention focused on the computer screen. Similarly, the empty-filled illusion has also been shown to be greater in young children (Droit-Volet, 2008). When confronted with empty durations, children must not become distracted during the interval between the two signals; that is, they must wait without doing anything.

In conclusion, young children, in the same way as animals, possess a basic mechanism that allows them to process time, but the development of the abilities to judge time in different contexts is dependent on the development of attention and executive functions. What is time? The answer is 'a quantity of information that has to be captured in time'.



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