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DEVELOPMENT OF TIME-SPACE PERCEPTION IN (A-)TYPICAL CHILDREN: ANALYSES OF INTERFERENCES AND MODELLING.

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PORTEUR

Quentin Hallez est maître de conférences HDR en psychologie du développement à l'UR DIPHE depuis 2020, spécialisé dans la perception du temps

COMPÉTENCES

A publié 24 articles dans des revues reconnues dans la discipline : Scientific Reports ; Journal of Experimental Education ; Emerging Adulthood ; British Journal of Visual Impairment ; Journal of Epidemiology and Population Health ; Timing & Time Perception ; Behavior Research Methods ; Frontiers in Psychology ; Journal of Eating Disorders ; Applied Psychology…

A obtenu son HDR en 2024 : « A la recherche du temps perçu : développement, interférences et applications pratiques »

PROJET

Contexte d'émergence : La durée temporelle est un aspect fondamental à tout événement physique. Il est essentiel pour presque tous les comportements que nous adoptons, de la planification à l'exécution des actions. L'engouement pour découvrir comment le cerveau traite le temps a favorisé la publication de modèles sur la perception du temps appelés « horloge interne ». Ces modèles ne prennent pas en compte l'influence spatiale lors du traitement temporel alors même que les chercheurs ont montré que ces dimensions peuvent s'influencer mutuellement.

Objectif principal : Le projet vise à **étudier les interactions entre perception du temps et de l'espace**, pour les modéliser.

- Approche développementale (étude à travers les âges) et interdisciplinaire.
- Pupulation générale et handicap sensoriel (cécité)

Objectif secondaire : créer un **nouveau modèle d'horloge interne** intégrant les effets spatiaux.

- Reproduire des estimations temporelles d'enfants et d'adultes.
- Améliorer notre compréhension des mécanismes cognitifs du traitement du temps.

Financement : 207 462 €

CONSORTIUM

La force du consortium réside dans l'assemblage d'une **expertise multidisciplinaire et complémentaire**, directement pertinente pour l'étude du développement de la perception du temps et de l'espace chez le sujet avec et sans déficience visuelle. Le partenariat combine une expertise thématique approfondie dans des domaines clés. En somme, la valeur ajoutée du consortium réside dans cette synergie d'expertises thématiques, d'accès à la population et de compétences méthodologiques, créant un environnement de recherche optimal pour l'étude complexe de la déficience visuelle chez l'enfant.

DIPHE Université Lumière Lyon 2	emc	lapsco laboratoire de psychologie sociale et cognitive	Laboratoire de psychologie université de BORDEAUX	University of Manitoba
 **Nicolas Baltenneck** MCF, expert en représentation spatiale et action spatiale chez les sujets aveugles (WP1 et 4)  **Anna Rita Galiano** PR**,** directrice du laboratoire DIPHE, spécialiste du développement des enfants déficients visuels (WP3 et 4)  **Dannyelle Valente MCF**, contact avec les associations et établissements pour faciliter le recrutement d'enfants avec déficience visuelle (WP3 et 4)	 **Anders Royce, Université Lyon 2,** MCF responsable en modélisation bayésienne et réseaux neuronaux appliques a la cognition (WP2 et 5)	 **Florie Monier, Université Clermont Auvergne,** MCF, experte dans le domaine du développement de la perception temporelle et des habiletés motrices (WP2 et 4)	 **Joanna Lucenet, Université de Bordeaux,** MCF, experte en psychologie du développement cognitif (WP1 et 2)	 **Fuat Balci, Université du Manitoba, Canada,** PR, expert externe international (WP1, 2 et 5)

Development of Time-Space Perception in (A-)Typical Children: Analyses of Interferences and Modelling.

Table1. **Summary table of people involved in the project:**

Partner (affiliation)	Name	First name	Current position	Role & responsibilities in the project (4 lines max)	Involvement (person/month) throughout the project's total duration
Lyon 2 University (DIPHE laboratory)	Hallez	Quentin	Permanent: lecturer	Investigator of the project, joint leader between all WPs, communication and publications (WP1, 2, 3, 4 and 5)	38.4 P/M
Lyon 2 University (DIPHE laboratory)	Baltenneck	Nicolas	Permanent: lecturer	Expert in spatial representation and spatial action in blind subjects (WP1 and 4)	12 P/M
Lyon 2 University (DIPHE laboratory)	Galiano	Anna-Rita	Head of DIPHE laboratory Permanent lecturer	Leader in differential psychology and sensory impairments (WP3 and 4)	12 P/M
Geneva Lyon 2 University (DIPHE laboratory)	Valente	Dannyelle	Permanent lecturer	Expert in the field of visual impairment. (WP3)	9 P/M
Lyon 2 University (EMC laboratory)	Anders	Royce	Permanent lecturer	Leader in Neural network modelling applied in cognition (WP5)	7.2 P/M
University Clermont Auvergne (medical school)	Monier	Florie	Permanent lecturer	Expert in the field of development of time perception and motor skills (WP2 and 4)	9 P/M
University of Bordeaux	Lucenet	Joanna	Permanent lecturer	Expert in developmental psychology, specifically in cognitive development (WP1 and 2)	9 P/M
			Non-permanent: PhD student	Participant recruitment and behavioural assessment (WP1 and 2)	36 P/M
			Non-permanent: Research Assistant	Participant recruitment and behavioural assessment (WP3)	8 P/M
University of Manitoba (Canada)	Balci	Fuat	Associate professor	Expert (WP1, 2 and 5)	International external expert

Any changes that have been made in the full proposal compared to the pre-proposal:
New collaborator: With the aim of opening an international perspective to our team, professor Fuat Balci (University of Manitoba, Canada) has joined the team as an International external expert. His highly valued expertise in time perception and computational modeling will be of great help for this project for the work packages WP1, WP2 and WP5.
Experiment modification: In the last version of our project, one of our experiments proposed to bias visual space perception with prismatic glasses. However, the perception bias to the right or to the left will not generate differences in the spatial gap between two stimuli. The use of these prismatic glasses may therefore not reduce the confidence of vision. We have instead proposed another study (study 1b), based on an increase in the difficulty of the visuo-spatial task to increase the uncertainty related to this dimension and thus the interference between perceptions of space and time that will occur.

1. Pre-proposal context, positioning, and objectives

1.1. Objectives and research hypothesis

Temporal interval is a fundamental aspect of any physical event – there is no event without duration. It is an integral part of almost all behaviours we engage in, from planning to executing actions. Besides the action itself, timing abilities also allow for the anticipation of sensory events, therefore conveying obvious survival benefits. This is not a small matter; the psychological processing of time has so many practical implications (e.g., from movement, social interaction, life satisfaction to mental health, and so on) that in 2005 the journal of Science identified it as one of the major scientific questions of the millennium. The enthusiasm for discovering how the brain processes time has generated various models on time perception called “internal clock” (for a review, see Wang & Wöllner, 2019). According to most leading models, time is processed within a cognitive architecture that is solely dedicated to keep track of time. This is a simplistic approach to the isolated conceptualization of internal clock. To this end, recent work suggests that timing does not involve a centralised clock, but on patterning within a distributed network rather than involving a centralized clock (Hallez & Droit-Volet, 2017, 2019). Furthermore, researchers have proposed that time and space are not processed independently and thus can strongly influence each other (Johnston et al., 2006). This assertion is supported by numerous brain imaging studies that point at the shared neural underpinnings of temporal and spatial representations (Eagleman et al., 2005). Although it has been an accepted scientific fact in physics for almost a century that the passage of time can be modulated (e.g., speed up or slowed down) depending on factors that affect space (e.g., gravity and motion), these elements of the theory of relativity have not been sufficiently integrated into the study of the psychology of time. The present project aims to provide insights into the interactions between time and space perception within this relational framework. Crucially, we will study these aspects from a developmental point of view, through an interdisciplinary perspective (i.e., developmental psychology, experimental and differential psychology, cognitive sciences, cognitive neuroscience, and computational modelling). There are two alternative accounts of the relationship between representations of time and space, and our experimental hypotheses will be based on the symmetric perspective.

Asymmetric hypothesis (AH). The asymmetric interaction hypothesis is primarily based on the Conceptual Metaphor Theory (Lakoff & Johnson, 1980). According to this view, people employ spatial metaphors to think or talk about time in such a way that they use their concrete spatial experience to support their understanding of the abstract processing of time (Boroditsky, 2000). In other words, agents use metrics of spatial representations to structure temporal representations but not vice-versa. This hypothesis has been supported by many behavioural evidence regarding the effect of space on time, but no effect of time on space (Casasanto & Boroditsky, 2008). This view implies that time and space are not processed by a common cognitive mechanism. Thus, it does not really undermine existing clock models, albeit none of these models include the interference of space when processing time. *Assumption1 AH*: Space affects time perception more than time affects space perception. *Assumption2 AH*: Symmetry in the development of space and time representations is not necessary. *Assumption3 AH*: Temporal and spatial information are processed in different neuro-cognitive substrates and should not share common attentional resources.

Symmetric hypothesis (SH). The symmetric interaction hypothesis was initially proposed by Walsh in

2003 in his ATOM theory (A Theory Of Magnitude). ATOM theory offers a unified sense of magnitude that underpins all reasoning about space, time, and numerosities. This hypothesis has been widely supported by brain imaging studies showing similar activations when processing time, space, and numerosities (Eagleman et al., 2005; Eichenbaum, 2017). Nonetheless, studies in developmental psychology have challenged this view, showing specificities in the development of number sense (Leibovich et al., 2017; Odic, 2018). These researchers have therefore concluded that numbers are specific compared to the continuous dimensions of time and space, without systematically verifying their assumption. Since then, very few behavioural studies have provided evidence against asymmetric space-time mapping (Loeffler et al., 2018).
Assumption1 SH: Time affects space perception more than (or as much as) space affects time perception. *Assumption2 SH*: Symmetry in the development of space and time representations is necessary. *Assumption3 SH*: Temporal and spatial information are processed in a common neuro-cognitive substrate and should share attentional resources.

The project's goal and the developmental perspective. This project aims to provide developmental insights into the relations between perceptions of time and space. Piaget (1952) already proposed in his theory of cognitive development that children from 2 to 7 years old go through different developmental stages in their understanding of space and time, and that their abilities improve with age. These assumptions are now supported by many contemporary researchers, which demonstrated that estimates of both space (Kirkham et al., 2002, 2007) and time (de Hevia et al., 2014; Sciutti et al., 2014) become more precise but also less variable (i.e., intra-individual variability) with age. A developmental perspective therefore seems fundamental to the analysis of the factors of possible change that may emerge in the mutual interferences between time and space during childhood. This approach is key to more fully, conceptually, and empirically exploring the nature of the overlap between time and space processing, its developmental trajectory, and how it really works. The population of our studies will mainly comprise children between 5-8 years of age, since temporal representations are established between these ages and reach adult states at the age of 8. To more deeply analyse the relationships between perceptions of time and space, we will also involve children with visual impairments, as this population have further difficulties in building representations of space when compared to sighted children (Cappagli et al., 2017; Valente et al., 2021). Crucially, to our knowledge, no prior study has investigated time perception among blind children. The final aim of this program is to provide a new internal clock model with a cognitive architecture that predicts spatial interference and can reproduce the real temporal estimates made by children and adults. The set of largely untested hypotheses proposed in this program could greatly improve understanding of the mechanisms underlying interference effects and contribute to our fundamental understanding of how humans process magnitudes.
The objectives of this project have been categorised into five distinct Work Packages (WP). WP1 will tackle Assumption 1 in investigating whether time affects space more than, or as much as, space affects time, using different modalities. WP2 will test Assumption 3 in investigating whether temporal and spatial information are processed by a common neuro-cognitive substrate and share attentional resources. The WP3 will test Assumption 2 by exploring the development of spatial and temporal skills in children with visual impairments, while WP4 will rely on this assumption to explore whether time (or space) perception can be promoted by improving space (or time) perception. Finally, to propose a new model of temporal and spatial judgements in a fashion that also is developmentally applicable, the objective of WP5 will be to develop a time-space model by carrying out neural networks modelling. The following sections will describe in more detail how each task of the present project has been designed to fulfil these objectives. Before doing so, we will present some key findings obtained by several researchers including some of our team. This background information will help to explain the rationale behind each task of the project.

1.2. Position of the project as it relates to the state of the art

The interdependencies in perception of spatial and temporal dimensions of a stimulus dates to several decades ago. In early studies (Cohen et al, 1953; Helson, 1930; Helson & King, 1931), three stimuli were presented sequentially using three light bulbs on a wall. The sequential light flashing between the three bulbs thus created two space-time intervals (i.e., between the first and the second light bulbs and between the second and the third light bulbs). With this method, researchers demonstrated that the spatial interval between two light bulbs was perceived as longer if it was concurrently accompanied with a longer temporal interval. This effect, better known as the *tau* effect, have been extensively investigated and replicated (for a review, see Grondin, 2010), showing that the longer the distance between the stimuli, the longer the perceived time interval. Reciprocally, the time interval between two stimuli is perceived as longer if it is concurrently accompanied with a longer spatial interval (the kappa effect). It has long been proposed that this task led people to attribute a uniform movement to successive stimuli, which created the dependencies between space and time (Jones & Huang, 1982). However, this effect is not unique to spatial perception of an empty interval (e.g., space estimated from stimuli that are presented sequentially) but has also been demonstrated over length perceptions (e.g., space estimated from a spatially filled stimulus). For example, Cai and colleagues (2018) showed that reproduced durations increased as a function of the length of a segment. In other words, interdependencies between time and space are observed, even when the task does not introduce imputed motion (Binetti et al., 2015, Casasanto & Boroditsky, 2008, Merritt et al., 2010, Starr & Brannon, 2016). Thereby, it has been proposed that, spatial interval, whether empty (e.g., space) or filled (e.g., length) exhibit common features regarding the interdependencies between space and time. This is an important statement since it brings up to date the question of asymmetry and symmetry between time and space.

1.2.1. WP1: Developmental analysis of time-space interferences depending on sensorial modalities.

(to test Assumption 1 SH and refute AH).

Rationale. When reviewing the literature dealing with the (a-)symmetry of time and space, it is obvious that there is no clear consensus on the connections existing between temporal and spatial representations (Winter et al., 2015). Yet, both hypotheses received considerable supports from empirical results (Agrillo and Piffer, 2012; Bottini and Casasanto, 2013; Coull et al., 2015; Skagerlund et al., 2016; Xue et al., 2014). A recent but growing body of evidence suggests that the interference between the perceptions of time and space highly depend on the sensory modality by which the stimuli are processed (Loeffler et al., 2018). In other words, research concluding the existence of an asymmetric space-time interference included studies based on the visual sensory modality, while studies favouring the symmetrical approach mainly used auditive sensory modalities. Indeed, it has been previously stated that visual information processing shows higher sensitivity to spatial information but lower sensitivity to temporal information while auditory information processing shows enhanced sensitivity to temporal information but lower sensitivity to spatial information (O'Connor & Hermelin, 1972; Recanzone, 2009). To bridge these two patterns of results Cai and colleagues (2018) proposed a Bayesian modelling and concluded that, the noisier a dimension, the more sensitive the cross-dimensional interference. In other words, time-space interference would depend on the amount of representational uncertainty; the noisier the rated construct, the less reliable it is, and the stronger space-time interference.
The study of time-space interference in children is motivated by this Bayesian-framework dependent assumption. Indeed, before the age of 7-8, researchers documented that the representations are not fully mature, leading to noisier representations of both time and space. Consequently, children should show enhanced interference effects, both from space on time and from time on space and independently of the modalities. Indeed, someone could expect these continuous dimensions of space and time to be intertwined in younger children (or at least, more pronounced) as noise in their temporal and spatial representations leads this population to a lot of uncertainty and thereby, to higher space-time interference. These results would thus be to the advantage of the assumption 1SH, as opposed to 1AH. Recently, Vidaud-Laperrière and his colleagues (2022) demonstrated in adults that the effect of space on time is more pronounced in individuals with high sensitivity of space (low Weber Ratios and quick reaction times in temporal discrimination). Thereby, the more certainty in space, the higher the space-time interference on time perception.
To investigate the development of space-time interference and tackle the Assumption 1SH vs 1AH, three different studies will be carried out. **Study 1a** will aim to investigate the development of time-space interference in visual and auditory modalities, which is unprecedented. Consequently, the aim will not be to directly compare both modalities, but to appreciate the developmental interferences observed in both modalities. We will thus be able to analyze, in a developmental perspective, the influence of

individual temporal and spatial sensitivity, on the space-time interference. As we saw that vision is the least favorable modality to create an interference of time on space perception, **Study 1b** will aim to investigate, within the visual modality, the influence of task difficulty through ages. In other words, it will allow us to analyze, from a within subject point of view, the influence of the modulation of the spatial sensitivity and its repercussions on the related space-time interference. Finally, we will come up with a whole new method in **Study 1c** to analyse, in a systematic way, the space-time interference for both space and time reproductions, through visual and auditive modalities. Here the objective will be to compare modalities.

1.2.2. WP2: Analysis of the development of interference between time and space

(to test Assumption 3 SH and refute AH).

Rationale. One could wonder whether the superiority of space over time could stem from differences in cognitive demands across the spatial and temporal tasks. Indeed, temporal tasks used in the literature are often much more difficult and more resource-demanding than spatial ones, thus entailing less precise but effortful judgments.

In addition, if the interference is related to reduced cognitive abilities, then, this would inform us about how these interactions occur. According to most magnitude perception models, the processing of sensory information follows a series of three successive stages. The first one corresponds to the encoding or accumulating stage, where the sensory information is registered into a neural format. The second on consists in the memory stage, where the information is maintained and, if needed, retrieved. Finally, in the response stage, the retrieved mental quantity is compared with another magnitude. Each stage is a possible source of interference. It therefore seems important to elucidate where and when the interference caused by the simultaneous treatment of time and space occurs. To better situate the issue, we will present the most commonly-used internal clock model, namely the pacemaker accumulator proposed by Gibbon and colleagues (Gibbon et al., 1984). It is important to note that there are other variants of this model (Treismann, 1963; Zakay & Block, 1994) and other internal clocks (for a review, see Wang & Wöllner, 2019; Balci & Simen, 2016). Yet, none of these models have been unanimously approved (Ivry & Schlerf, 2008).

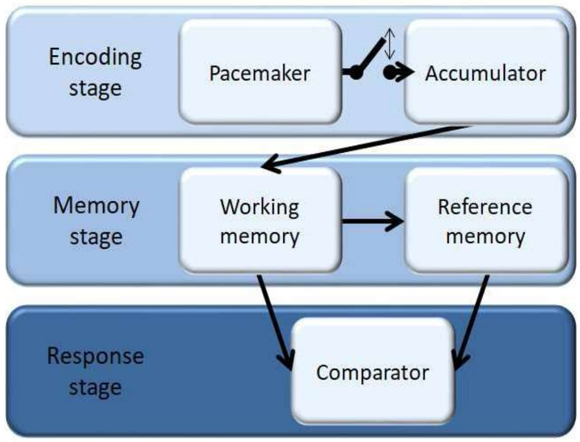


Figure 1. Diagram of the pacemaker- accumulator model (Gibbon et al., 1984)

According to the pacemaker-accumulator model, illustrated in Figure 1, agent is equipped with an "internal clock", composed of a pacemaker, a switch, and an accumulator. At the onset of the to-be-timed stimulus, the switch closes (acting as an attentional gate), thereby allowing the pulses generated by the pacemaker to increment in the accumulator. At the offset of the same stimulus, the switch opens and pulses are no longer transmitted to the accumulator. Thus, the perceived duration directly depends on the stored pulses. In other words, the perceived duration increases with accumulated pulses. According to attentional models of time (Zakay, 1989, 1992; Zakay & Block, 1996), the more attentional resources divert away from the passage of time, the shorter the perceived duration. A decrease of the attention allocated to the processing of time increases the latency relative to the closing of the switch underlying additive effects and/or its flickering during the duration processing (i.e., going from an open to a closed state) underlying proportional effects. This state change of the switch implies that all the pulses emitted cannot be communicated to the accumulator, and that time units are lost in the integration process. As a consequence, fewer impulses are stored and time is underestimated.

The processing of counted pulses can then follow two non-exclusive paths. If the duration is considered important for later judgments, it will be stored in long-term memory (known as reference memory). If it is considered less important, then it is sent directly to a short-term memory system (known as working memory). When the time information passes into the reference memory, it undergoes a transformation by a constant k*. Finally, the decision-making processes are found at the last level of processing determining the behavioral manifestation of temporal representations. This stage may be particularly critical when comparing two identical dimensions (i.e., two durations for example). Therefore, researchers usually analysed this stage when using categorical judgements (Rammsayer & Verner, 2014). Yet, decision making could also influence the simultaneous treatment of multiple continuous magnitudes (Yallak & Balci, 2021). The work of Fuat Balci, external researcher and member of the consortium, notably showed a positive correlation between the ability to monitor metric errors and the variability in estimations or reproductions, as assessed through the combination of confidence and error direction judgments, in temporal, numerical and spatial domains.

To sum up, according to the temporal information processing models, the interference between time and space may arise in any of the three different stages. Indeed, each one has been previously proposed as the locus of cross-dimensional interactions (Cai et al., 2018; Hamamouche et al., 2018; Vidaud-Laperrière et al., 2022; Yallak & Balci, 2021). With the aim of locating the source(s) of the interference, as well as the weightings associated with each of these sources, **Study 2a** will aim to analyze, through a longitudinal study, the weight of the development of individual cognitive functions (e.g., memory, attention, processing speed) on interferences during the simultaneous processing of time and space. In addition, measures of certainty will be taken for each of the estimates. **Study 2b** will further investigate the effects of interference that can be source localized to memory, with a procedure where the subject will or will not have to wait before giving their answer. Taken together, these studies will shed light on the assumption 3AH vs SH and will provide information about the cognitive factors that may be responsible of time-space interference. By doing so, we will also have information to locate the interference (e.g., if it occurs in encoding, memory or response stages) and thus be able to better model the behavioural phenomenon of interest.

1.2.3. WP3: Analysis of atypical space-time development: the case of visual impairment

(to test Assumption 2 SH and refute AH).

Rationale. Previous research has shown that vision plays an important role in spatial encoding. According to the general loss hypothesis, vision is the only sense capable of encoding spatial information (Eimer, 2004). Numerous studies have confirmed this idea, showing that congenitally blind subjects display poorer performance in various spatial tasks, through diverse modalities including auditive (Gori et al., 2014; Kolarik et al., 2013; Zwiers et al., 2001), haptic (Postma et al., 2008), and imaginative visual spatial (Postma et al., 2007). A more recent hypothesis, the inter-sensory calibration hypothesis (Gori et al., 2008; Thinus-Blanc & Gaunet, 1997), suggests that the spatial impairments exhibited by blind people can be explained by assuming that during early development, vision calibrates the other senses to process spatial information. Note that, according to the authors, this calibration mechanism between the senses and driven by vision must take place during the first years of life. If vision loss occurs after the critical visual calibration period, then the development of spatial cognition will be less severely affected. Developmental studies validate this hypothesis, showing a deficit of spatial representations, as well as better results when blindness has occurred later in life (Thinus-Blanc & Gaunet, 1997). This is precisely the reason why in this WP, we will be working with congenitally blind people. Consequently within this WP, the results for blind children will be systematically compared with those of sighted children (matched for age and sex), shedding light on *Assumption2 AH vs SH*.

This WP has two distinct aims which refer respectively to studies 3a and 3b. Study 3a will aim to census the development of time perception in blind children. This is an important topic because, to our knowledge, no study has yet addressed the development of temporal capacities in blind subjects. Our objective will therefore initially be to trace the developmental trajectories of this population with regard to these temporal representations. The temporal development of children without impairment has, on the other hand, been clearly defined (Droit-Volet, 2011, 2013, 2016). From a theoretical point of view, it has been clearly established that, regardless of the type of task employed, performance in temporal judgments and productions improve with age. Indeed, we can observe an improved accuracy (that is, a lower difference between real and estimated duration) as well as a reduction of variance with age, particularly in subjects between 5 and 8 years of age. Recently we succeeded in identifying age thresholds in time sensitivity above which no further changes are observed, thus indicating the attainment of maturity in timing abilities (Hallez & Droit-Volet, 2020). Thus, the first objective will be to draw developmental trajectories of time perception in blind children and to compare this with children without visual impairment. According to both symmetrical and asymmetrical hypotheses, children born blind should have lower temporal skills since they show delay in the development of spatial cognition.

The objective of **Study 3b** will be to examine the space-time interference in blind individuals and compare this population with sighted persons (children and adults). Here, we assume that blind children would generate further interference of space on time in comparison to sighted children because audition is a privileged modality of the apprehension of space in these individuals. We will also analyze whether these effects can be measured using self-report of their confidence in the spatial and temporal estimation for each production. If we find such results, this could therefore attest to the influence of certainty or confidence in one dimension on the judgment and on the resulting interference.

1.2.4. WP4: Mediation; experiencing time to improve space perception?

(to give additional support to Assumption 2 SH and propose mediation).

Rationale. Our ambition is not only to analyse interindividual differences in the development of spatial and temporal cognition, but also to reduce these differences by developing possible mediations. Recently, Florie Monier, one of our team members, developed a protocol for learning durations by acting (for example with tapping tasks), based on prior exploratory work (Droit-Volet & Rattat, 1999), and found beneficial effects in improving the perception of time (Monier et al., 2019). The aim of **Study 4a** will be to analyse, using a tapping protocol, whether an improvement in the temporal representation allowed by this task, would affect positively spatial perceptions. This will therefore be a direct behavioural effect showing the symmetrical relationship between time and space (based on Assumption 2SH). On the other hand, and if there is a symmetry between time and space, then we should also be able to expect the opposite result. The aim of **Study 4b** will be reversed, as it will aim to test whether improving the perception of space in children can improve individuals' time perception. The objective will be to use an already validated audio motor training which improves the mobility and spatial of children to explore whether it can improve temporal representations (Cappagli et al., 2019). In sum, the methodologies proposed here will be used to investigate whether we can improve space (or time) perception by improving the representations linked to the dimension of time (or space).

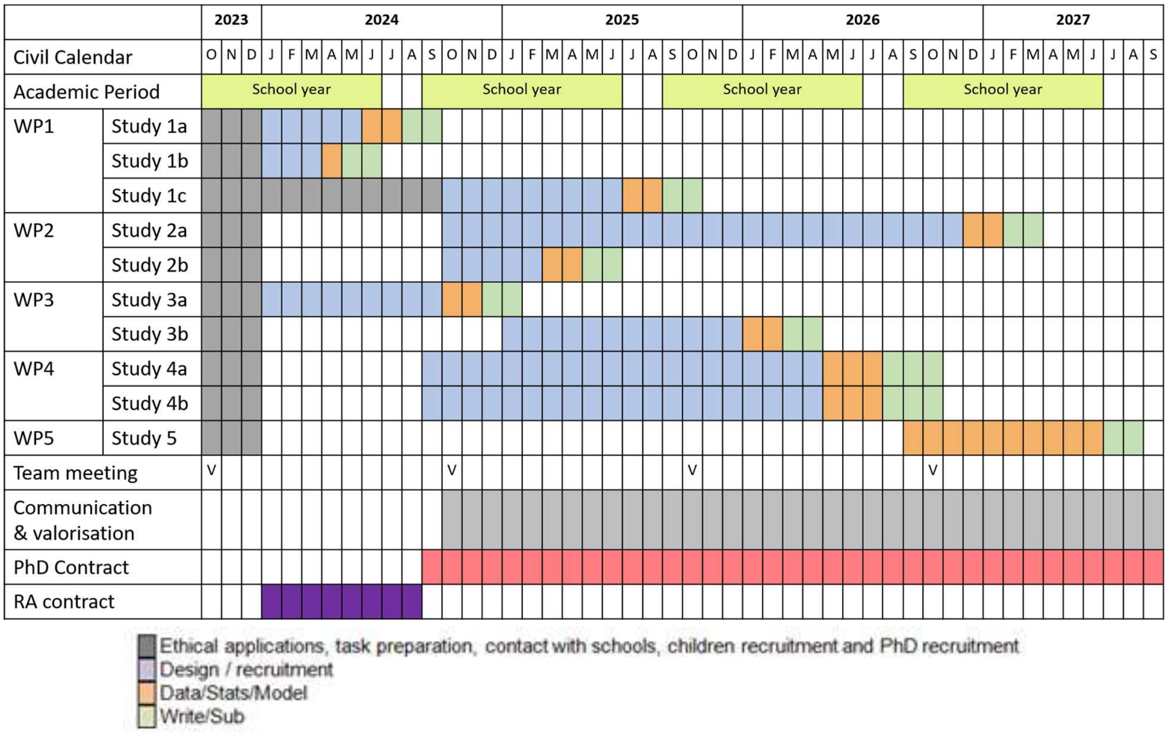
1.2.5. WP5: Constructing and validating space-time neural network model.

(to model our data according to the findings)

Rationale. Artificial Neural Networks (ANN) are forecasting methods, that emulate a biological neural network. Although they do not approach the complexity of the brain as they use a reduced set of concepts from biological neural systems (Park & Lek, 2016), they allow, by their inherent structure, an appropriate adaption to complex nonlinear relationships between the response variable and its predictors. Since the 80s, ANNs have been largely developed and successfully applied in various fields (Park & Lek, 2008), including cognitive modelling (Thomas & McClelland, 2008), to such an extent that they are now considered as universal approximators (see Gelenbe et al., 1999). Our aim will be to propose a new ANN of time processing, able to predict the interferences linked to the processing of spatial information, while taking into account the cognitive aptitudes of the participant, so that it is also viable from a developmental point of view. If all our studies support the symmetry hypothesis, which is what we expect, we will create a new model of space-time processing capable of simultaneously estimating space and time accounting for the two-way interference and the cognitive abilities of the subjects, always keeping in mind the functioning of this model from a developmental or clinical point of view. It is noteworthy that model validity can be better controlled for when estimating two dependent variables simultaneously (Turner et al., 2016), which this framework would allow. This work package will thus be the final step in our program, as it will first require real human data collection among both children and adults, and in-depth information regarding the effects of interference and the mechanisms at the root of these effects in order to most appropriately design the ANN (for further information about the design ideas of the ANN related to this project, see section 1.3.5).

1.3. Methodology and risk management

Table 2. **Gantt chart**



This is a 48-month project, with some tasks beginning early and others later in line with their methodological constraints and interdependencies. The planning of work packages and deliverables is summarized in the Gantt chart (Table 2). We will first detail the methodologies associated with the studies contained in each of the 5 WPs. Then, we will describe the initial steps required to achieve the research objectives. These tasks will require the contribution of all permanent team members. Finally, a last sub-part presenting the scientific risks and fallback solutions will close this section.

1.3.1. WP1: Developmental analysis of time-space interferences depending on sensorial modality. *Team: Q. Hallez, J. Lucenet, N. Baltenneck & F. Balci. (Exp., Cog. and Dev. Psychol.)*

Study 1-2. n ≥ 25 participants for each of the 4 age groups (5, 6 and 7 years old as well as adults). Sample size was determined using effect sizes from previous research examining space-time interference on adults (Starr & Brannon, 2016; effect size f = .80, with power (1 – ß err prob) = .95, and α = .05), for a main experimental design that has two within-subjects factors [durations; spaces] and one between-subjects factor [age] (G*Power, Faul et al., 2007). As we expect a higher interference effect in children, it is legitimate to use these data as a first baseline.

In a typical temporal bisection task, the procedure is divided into two phases for both space and time estimations. For instance, in a temporal bisection task, participants first learn to distinguish between a short duration (600ms) and a long one (1200ms) based on the delay of appearance between two dots. In this phase, participants receive positive or negative feedback depending on the accuracy of their response. After a series of 12 trials, participants automatically move on to the testing phase if their correct answer scores are above 70%. In the testing phase, feedbacks are no longer given, and intermediate values are incorporated (750, 900; 1050ms), along with the two anchors (short and long stimulus). The participants are not aware of this change, they must answer “Short” or “Long” if they think they experienced the short or long duration, respectively. The experimenter can then transcribe the participant's oral responses by hitting the S or L keys on the keyboard (for short or long responses, respectively).

Study 1a. This experience will be divided into two sessions counterbalanced between participants: a session based on visual stimuli and a session based on auditory stimuli.

Visual session. In this session, participants will perform both a temporal bisection task and a spatial bisection task, independently. The order of the two tasks will be counterbalanced between the participants. In the visual session, the perception of time will depend on the duration separating two black dots of 0.8° in diameter on a gray background. By contrast, the spatial perception will depend, in turn, on the space separating these two dots. In the training phase, short and long durations will be of 600 and 1200ms for the temporal bisection task as well as 5 and 10 inches for the spatial bisection task. Then in the testing phase, 3 additional durations or spatial interval will be integrated, depending on the bisection task (e.g., 750; 900 and 1050ms for the temporal bisection task and 6.25, 7.5 and 8.75 inches for the spatial bisection task). To induce temporal-spatial interference, the two anchors (i.e., short or long stimuli) of the irrelevant dimension (space for the temporal bisection task and time for the spatial bisection task) will be added. Within the temporal bisection task for instance, only the two spatial anchors will be used (5, 10 inches), while the temporal estimation will rely on a total of 5 durations [600; 750; 900; 1050 and 1200ms]. Conversely in the spatial bisection task, the two temporal anchors [600 ; 1200ms] will punctuate the presentation of the 5 different spatial intervals (5, 6,25; 7,5; 8,75 and 10 inches). Note that the starting point will differ throughout the experiment, so that the participant cannot memorize exact locations, but has to calculate the space for each trial.

Auditive session. The procedure will similar to the visual session. However, the time estimates will be based on an interval between two beeps of 440 Hz spatially broadcast in space. Regarding the spatiality of the sound, it is currently impossible to precisely locate a sound in space using existing tools. Nevertheless, other things being equal, a recording from a tascam microphone and speakers placed in an arc around the microphone would allow us to create a relative auditory spatiality (see Figure 2). If the durations will be identical as those presented in the previous session, the spatial duration will consist in a short (8 degrees), and long space interval (40 degrees). These spatial intervals will be pre-tested in children so that they are not too hard or easy.

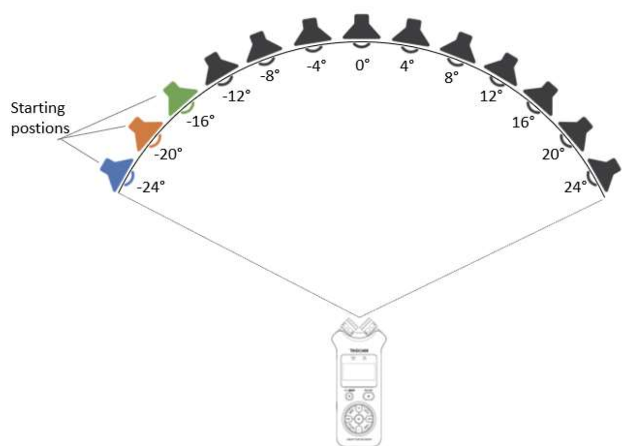


Figure 2. Graphical representation of the space registration process

Expected results: Note that our goal in this study is not to directly compare the auditory session to the visual session. Indeed, the spatial intervals presented not being strictly similar, the conclusions would be risky. Rather, the objective is to compare the effects of time-space interdependencies on spatial and temporal estimates through development on both modalities. Therefore, we hypothesize that the space-time interference would be more accentuated as the children are young, both in visual and auditive tasks. Indeed, we expect the dimensions of time and space to be intertwined because the representations of children are noisier.

Study 1b. This experiment aims to analyze, at the within-subject level, the effect task difficulty (i.e., increase in spatial uncertainty) on space and time interferences during development. The task will be designed in the same lines as in Study 1a, except that the two sessions (i.e., auditory and visual) will focus on the visual modality, in two contexts of difficulty (easy vs. difficult). The spatial intervals will consists in 1.6°, 4.4°, 7.2°, 10.0°, and 12.8° in the easy context and in 3.2°, 3.6°, 4.0°, 4.4°, and 4.8° in the difficult context (based on Vidaud-Laperière et al., 2022).

Expected results: At the within-subject level, we expect (i) a reduction of the effect of space on time in the difficult context, compared to the easy one, and (ii) a less pronounced effect in younger children, since the two dimensions would be intertwined for these participants.

Study 1c. n = 30 participants for each of the four age groups (5, 6 and 7 years old as well as adults).

The calculation of the participants is based this time on a plan with 3 within-subject variables, namely; time; space modalities and the between subject variable of age.

This study aims to analyze the effects of time and space using identical spatial intervals. In this experiment, the two modalities will be presented independently within a single session. Yet, participants will complete two different sessions; one for space and the other for time to limit task switching, known to be particularly costly for younger children. For this aim, we will develop a system where a series of 11 speakers will be placed in a straight line with a cross laser on their top. The objective is that the auditory stimuli (i.e., the sound coming from the speakers) and the visual stimuli (i.e., the light from the cross laser) can be presented on same spaces (cf Figure 3 – A). A projection canvas (represented in grey in the diagram) will be place in front of these speakers (cf Figure 3 – B), so that the child cannot keep the reference point in sight in the visual modality (to be more equivalent to the visual modality). Depending on the session, participant will be instructed to pursue a spatial or a temporal sequence. Thus, three stimuli (sound or light) will be sequentially presented to the participants and the participants will be asked either to continue the rhythm by pressing a buzzer button, or continue the spatiality by pointing on the canvas, with pointing laser (cf Figure 3 – C), where the last stimulus should have been presented. A camera, previously calibrated, will measure the distance between the two points at the request of the experimenter and the spatial error will be directly recorded (cf Figure 3 – D)

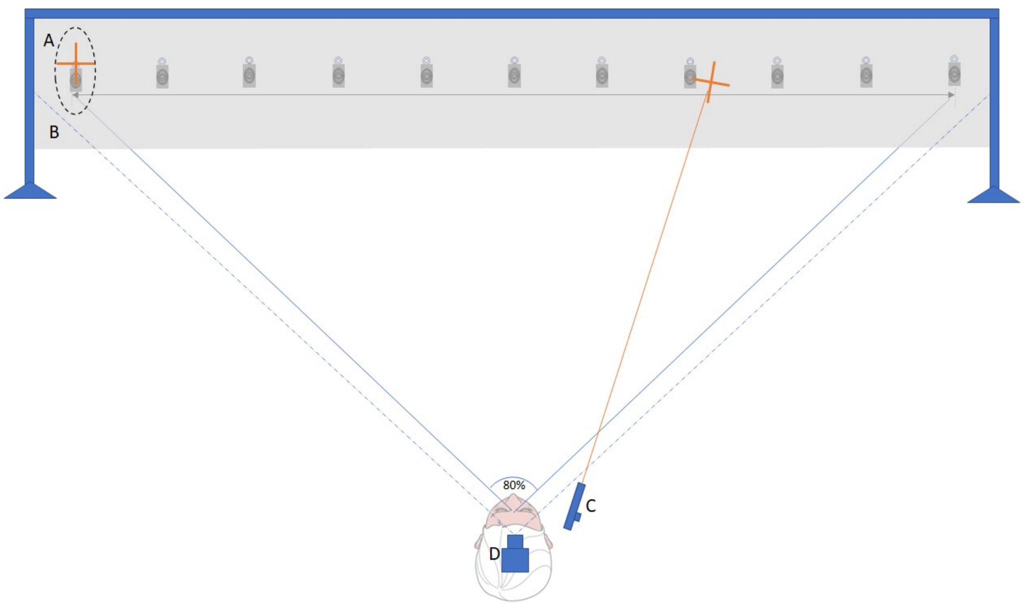


Figure 2. Diagram of the experimental design. With **A** illustrating one of the eleven speakers with laser cross delivering spatial and temporal stimuli; **B** representing the projection canvas; **C** representing the pointing laser necessary for the spatial reproduction and **D** the camera to measure the participant's space production.

Expected results: We hypothesize a modality effect in adults where (i) the effects of space over time will be stronger in the visual modality and (ii) the effect of time over space will be stronger in the auditive modality. We also expect that (iii) the modality effect would be attuned as children are young, as the effects of time and space are intertwined in this population.

1.3.2. WP2: Analysis of the development of cognitive functions on the effects of space-time interference. *Team: Q. Hallez, F. Monier, J. Lucenet & F. Balci (Cogn. Neurosci., Exp. and Dev. Psychol.)*

Study 2a. The originality of this study is to present a mixed method (combining longitudinal and cross-sectional designs). Fourty typically developing children will be recruited and distributed in two age groups, probably corresponding to 5 and 6-year-olds. However, age groups are likely to change depending on the findings obtained in Study 1a and 1b. For example, if the tasks do not seem too taxing enough for 5-year-olds, we would be very interested in the idea of adding a 3rd age group of 4 years old. Similarly, if our results evidence that space-time relationships does not develop gradually with age, but instead dramatically evolve over a year (which seems very unlikely), we will conduct a longitudinal study within this age range. To sum up, some technical aspects will determined in the light of the findings we will have collected. Similarly, for the methodology, if we demonstrate that the effects of time and space are intertwined in the youngest children independent of the modality, then we will focus on a single modality and more likely that of vision as it is very much easier to set up and to systematize spatial intervals.

This study is two folded. First, we aim to link the differences between the estimation tasks processed with one dimension (e.g., only time perception or only space perception) from that carried with the second dimension. To this end, children will perform four different tasks; a temporal estimation task alone and with the spatial dimension (the irrelevant dimension here), as well as a spatial estimation task alone and with the temporal dimension (the irrelevant dimension here). Thus, it will be possible to analyze the prior noise of a dimension within a single task treatment and its consequences in space-time treatments estimates when introducing the irrelevant dimension. Second, our goal is to analyze whether cognitive abilities contribute to the decrease in interference error caused by the addition of an irrelevant continuous dimension. To this end, children's cognitive abilities will be measured by neuropsychological tests. Again, the neuropsychological tests will depend on the used sensory modality. If the visual modality is relevant, the Child Attention Network Test (Child ANT; Rueda et al., 2004) will be used to measure three components of attention (i.e., alerting, orienting, inhibition), as well as visuo-spatial working memory task, the child-adapted version of the Corsi block tapping task (Kessels et al., 2000). In addition, for each of the estimates, the child will be asked to estimate the confidence related to their own estimate. This will allow us to visualize whether the weighting effects between space and time can be linked to metacognitive strategies.

Expected results: We first hypothesize that (i) children with lower attentional capacities would demonstrate higher levels of interference, for both spatial and temporal estimation. Indeed, as previously mentioned in the theory section, participants with lower attentional resources should not be able to treat both dimensions since the treatment would draw on a same pool of limited attentional resources. In addition, we hypothesize that the bias could occur also in the memory stage. Consequently, we expect that (ii) interference of both space and time on time perception and space perception would correlate negatively with individual working memory score (i.e., the lower the working memory score the higher the interference). Taken together, these hypotheses would give support to the Assumption 3SH and would assume that temporal and spatial information are encoded through a common pool of attentional resources and are stored together (or at least have a common "coding" and can interfere with each other in memory). Finally, we expect that (iii) higher levels of confidence in the estimation of one dimension would lead to higher interference on the opposite dimension in older children (but not at a younger age since time and space would be intertwined, as expected in WP1).

Study 2b. *n* = 25 participants will be sampled for each age groups (5, 6 and 7 years old). To explore more dezply whether a memory mix can accentuate the interference, we will analyze the effect of varying the time before which the participant can respond. In this study, participants will perform a visual reproduction task of either space or duration, while being exposed to the opposite dimension (i.e., the dimension that does not need to be treated). Within the same session participants will be allowed to respond, either immediately, or after a 30 second delay (within-subject variable). Note that we did not ask participants to make their decision twice (i.e., once immediately and then after 30 seconds) because participants could learn about their previous productions (Hallez et al., 2019). We will also analyze whether individual working memory abilities – measured with the visuo-spatial working memory task - could modulate this effect.

Expected results*:* We hypothesized that (i) trials in which individuals respond immediately would be more accurate than trials in which they are required to wait before giving their response. This decay effect of accuracy through retention interval has already been observed in the literature. Yet, we also expect (ii) the interference to be shifted toward the direction of the opposite magnitude. In other words, larger spaces induce larger time estimations, and lower spaces should lead to lower time estimations. According to Assumption 3AH, a similar effect should be observed for space estimations.

1.3.3. WP3: Analyses of atypical space-time development; the case of visual impairment. *Team: Q. Hallez, A.R. Galiano & D. Valente. (Diff., Exp., Cogn., Dev. Psychol.)*

Study 3a&b. n ≥ 30 participants will be sampled for each condition: 2 vision profile groups (children born blind [without other disorders] and sighted subjects) x 3 ages (4-6 years, 7-9 years and adults), ntotal ≥ 180. Sighted participants will be recruited to match for age and gender to our blind participants. These tasks will be programmed in python language in the form of an executable program inserted into a self-installation utility so that it can be directly carried out remotely on the participant's computer. To increase the number of participants in this study, the program will also be developed in French, English, Spanish, Italian, Portuguese and Turkish to be able to reach as many children as possible. By implementing accessibility measures in the context of blindness, participants will thus be able to carry out the experiment independently or in the presence of a guide, insofar as instructions and tutorials will be given orally during the experiment.

Study 3a. In this program, participants will perform a temporal bisection task (as described previously). This temporal bisection task will be performed twice, once with a range of short durations [500, 583, 667, 750, 833, 916, 1000ms] and once with a range of long durations [4000, 4667, 5333; 6000; 6666; 7333; 8000ms]. At the end of the individual handover, the data will automatically be sent to a designated protected personal cloud to which only members of the research consortium will have access.
Expected results: We expect greater variability and flatter psychophysical curves in blind children compared to children with vision, as supported by the Assumption 2 SH. This should be even more accentuated in blind children, as supposed by the inter-sensory calibration hypothesis.

Study 3b: In this experiment, blind and sighted individuals will perform the auditory bisection tasks (spatial and visual) presented study 1a. In addition, for each estimates, participants will self-report the certainty associated with the estimates they just performed.
Expected results: Congenitally blind participants are expected to (i) be less prone to time-over-space interference than sighted participants. This difference in interference should also be directly related to the higher confidence that blind participants would attribute to the spatial dimension in auditory modality. Yet, with regard to thesymmetric hypothesis (*Assumption 2 SH*), a correlation should still be observable between temporal and spatial accuracy across participants.

1.3.4. WP4: Mediation; experiencing time to improve space perception? *Team: Q. Hallez, N. Baltenneck, A.R. Galiano & F. Monier. (Diff., Exp., Cogn and Dev. Psychol.)*

Study 4a-b. $n \geq 25$ will be sampled in each condition of age (5years, 6years and 7years) and groups (experimental vs control) which leads to $n_{total} \geq 150$.

Study 4a. This experiment aims to analyse whether the implementation of a protocol aimed at improving temporal representations improves the child's spatial representations. To this end, participants will perform tapping tasks in which they have to coordinate a rhythmic tapping of the finger made by the dominant hand with a regular stimulus (Repp, 2005; Repp & Shu, 2013). Through this task, the skills of spontaneous motor tempo and synchronization are trained when the children are required to type in step with an external rhythm. Temporal continuation skills are also developed when the participants need to maintain the same rhythm after the removal of the external rhythm. To verify the influence of this training program on their perceptions of time and space, the children will be compared to other children who have not been following the training program on their abilities to visually reproduce durations and lengths.
Expected results: First, we hypothesize that children following the typing task protocol will have better abilities to estimate durations (Monier et al., 2019). Moreover, and as predicted by the *Assumption 2 SH*, an improvement in temporal representations shouldincrease spatial representations by reducing the spatial reproduction errors of the children who carried out the protocol.

Study 4b: The logic here is similar to Study 4a, except that we will try to develop the spatial representations in the auditory modality to improve children's perceptions of time. For this, we will use a space perception training protocol already validated in 2019 by Cappagli and his collaborators. Here too, there will be a control group, which will not carry out the experimental protocol, and an experimental group which will carry it out.

Expected results: First, we hypothesize that children following the space task protocol will show better abilities to estimate time, as shown by Cappagli et al., 2019 (note that they found these results on a blind population and this experiment will be run on sighted children). Moreover, and as predicted by the *Assumption 2 SH*, an improvement in spatial representations should increase temporal representations by reducing the temporal reproduction errors of the children who carried out the protocol.

1.3.5. WP5: Constructing and validating an internal clock neural network model able to predict time and space error. *Team: Q. Hallez, R. Anders & F. Balci. (Comp. model)*

This study will consist of performing neural networks modelling thanks to a Python dedicated toolbox. The design of the ANN will strongly depend on the empirical results throughout this 48-months project. We assume at this initial stage that the framework of a Simple Recurrent Network (SRN) would be the most appropriate test design for our model. SRNs are composed of three main structures called layers: an input layer (x), a hidden layer (h) and an output layer (y). In each of these structures, there are different units called neurons interacting non-linearly with each neuron of the previous and/or prior structure. They are called recurrent because the predictions that will be made for each trial (*t*) will be subjected to the weight of the preceding computation, by allowing the integration of a memory effect. This additional layer can thus memorise the previous activations of the hidden units to insert it again for the next computation. This loop thus allows for so-called “snowball” effects, allowing the neural network to predict the future depending on the past. In other words, this type of neural network is can determine the future in complex time series on the basis of the previous events encountered by the network. As timing is dynamic by essence, we assume that the SRN should outperform other NN frameworks that are less pertinent to the paradigm. SRNs have has already proved efficient for a wide range of dynamical perceptual and cognitive phenomena (e.g., facial recognition, language, serial recall) that also include top-down connection, necessary for anticipation and prediction processes (Mermillod et al., 2019) and we recently succeeded to simulate time perception in both children and adults using this structure (Hallez, Mermillod & Droit-Volet, 2023). To validate our new model, outputs of the model (e.g., both space and time predictions) will be compared to real data collected within the proposed research project. We will also be able to see if the developed SRN appropriately predicts unlearned cases, which would implicate that our NN model can generalize. These are, at this early stage, mere guesses and we can also advance to a deep learning paradigm if the performance of the simple NN model does not sufficiently satisfy expectations.

1.3.6. Initial steps required to achieved the research objectives

Team meeting organisation: As shown in the Table 2 above, annual meetings have been planned at pivotal moments of our project. These meetings will take place before the start of a school year and therefore just before the launch of our experimental protocols. In addition to presenting the organization of the project, particularly for the coming year, these moments of exchange will allow the researchers to discuss the problems they encounter, to share the new articles they have detected in the literature related to our research and present their results. Related experiences will thus be able to emerge, in addition to the experiences presented in this full-proposal. These meetings will take place on the site of the Lumière Lyon 2 University. A hybrid format will also be available for more distant researchers or for the event that one of the researchers is unable to travel.

Ethical applications: The present project includes testing children in non-invasive experiments, using standard procedures as well as standardized neuropsychological tests that are all in strict conformity with French directives. The research will be conducted in accordance with the principles embodied in the Declaration of Helsinki. As consequence, an application for ethical approval will be submitted to the ethic committee of the University of Lyon as soon as we receive a final decision from the ANR. These forms will be quickly written, given that the PI has already written such forms in the last 5 years. Besides and during the first year of the project, a declaration will be made to the French data protection authority (CNIL) regarding the protection of the collected data and the participants’anonymity.

Participant recruitment:

Typical children: The PI already works with many kindergartens and primary schools of Auvergne Rhône Alpes academies. The PI can also count on the support of consortium members of this project with Florie Monier and Joanna Lucenet, who also have ongoing projects in schools near their universities, in Clermont-Ferrand and Bordeaux, respectively. Therefore, our team have strong experience with administrative procedures and behavioural experiments conducted in schools (e.g., application forms for authorization for research studies in schools, contact with academy directors and district directors, writing/sending information letters to teachers and parents).

Children with visual impairments: The DIPHE laboratory has been engaged for several years in a strong partnership with medico-social establishments and associations specializing in the support of visually impaired children. Here is a non-exhaustive list of our partners: The Precoce Medico-Social Action Center of Villeurbanne, which accompanies children with visual impairment from 0 to 6 years old; the support service for the acquisition of autonomy and school integration from 6 to 20; "Les primevères", institute for the visually impaired located in Vaise which accompanies children with visual impairments from 6 to 20 years old, with or without associated disorders; the Federation ofthe Blind and Amblyopes of France; the National Association of Parents of Blind Children; the Valentin Haüy Association; Guide Dogs for the Blind; the GAPAS Visual Impairment Center; the Regional Technical Center for Visual Impairment (CTRDV); the National Institute for Young Blind People in Paris; The Dreaming Fingers Association; My Golden Hands Montclair Institute Association ;the Association for the Benefit of the Blind and Visually Impaired [Switzerland]; the Pedagogical Center for Students with Sight Disabilities (CPHV), among others. It is important to note that Nicolas Baltenneck, Anna-Rita Galiano, and Dannyelle Valente, who are all members of this project, have already published national and international scientific articles on children with visual impairments and are engaged in ongoing projects involving this population.

PhD, and research assistant recruitment: The present project is organized into nine experimental studies (and one computational study) which will require a significant amount of time in order to design the study, recruit participants, collect the data, launch statistical analyses, write articles, and/or disseminate the results publicly. Although the members of the consortium will devote significant research time to working on the project, it remains the case that the recruitment of other non-permanent team members, namely a PhD student and a research assistant for a total of 8 person-months, is also needed for the success of the project. Their contribution will be of great help to us, especially with regard to the collection of data with children, as the data collection process will be a very time-consuming activity. Indeed, (1) the tasks are systematically carried out individually, in the presence of the experimenter, (2) the measurements are repeated to gain statistical power with the consequence that the experimental handover can be long; and (3) the experimenter must travel to the establishment/schools to undertake data collection and synchronizes with the learning times offered by the school (respecting break times, for example). The idea of hiring a PhD student is supported by two different perspectives. First, from the project perspective, it will be a real time saver since it will be easier to have a single student PhD student to work on the different projects than to systematically train different research assistant for each year. Second, from a training perspective, the consortium thought that it could be a rich experience for the PhD student to work as a member of a team project. Furthermore, each of the permanent team members teaches on master's programs (i.e., in Developmental Psychology, Cognitive Psychology, Differential Psychology, and Experimental Psychology), which will facilitate the recruitment of non- permanent team members with strong backgrounds in the field. All members of the research team have extensive experience in the supervision of undergraduate and graduate students, as well as in mentoring and training research assistants.

1.3.7. Scientific risks and fall-back solutions.

Besides building further on the acquired expertise of the PI and its consortium on the development and time perception of children, all the team members are expert in reading research, so the project benefits from a very high level of methodological and scientific advances.

However, despite the important network inherent to this team (schools, academies, associations, medico-social establishments) allowing privileged access to children with and without visual impairment, some potential methodological risks still exist. The scientific risks and fall-back solutions envisaged are presented below.

Difficulties related to the task. Since we plan to repeat the measures, it is to be expected that the handovers may seem long for younger children. To overcome this, and to maintain the children's attention and motivation, we proposed two solutions here. First, the experiments will be systematically divided into several sessions of 15 minutes maximum. This will therefore reduce the disengagement, while minimsing the children's fatigue for the pursue of their learning day. The second solution will be to reward children's participation with small panini stickers (i.e., adhesive-backed cards featuring images of animals). Note that, to avoid any feeling of injustice between the children, stickers will also be distributed to children which are unable to carry out the experiment (for example, for children whose parents did not give their consent for their child's participation).

Recruitment. Our aim to focus on children and adults born blind constitutes a risk, because of the low prevalence of these cases. However, we believe that we can easily override this risk by opening the study internationally. This is precisely the reason why we have developed a method that can be carried out remotely. Indeed, this study will be translated into different languages and we will try to massively distribute these studies. In our consortium, researchers speak fluent English, Portuguese, Italian or Spanish and it will be easy together to give oral instructions in different languages. This will thus also allow the emergence of new partnerships overseas.

Data sharing between team members. All the data collected will be shared between the team members via a secure platform (for the analysis and publication process).

Statistical modelling. For WP5, we plan to build a neural network model. This approach requires specific expertise in mathematics and computational modelling. Three of the researchers in the consortium possess a background in mathematics and computational modelling and have already submitted/published articles in computational modelling (Q. Hallez, R. Anders, and F. Balci). This expertise in computational modelling will guarantee the success of this task.

2. Organization and implementation of the project

2.1. Scientific coordinator and consortium / team

Coordinator. The project manager is Quentin Hallez, a young lecturer (30 years old) working in developmental psychology at the Université Lyon 2, who has been an associate member of the DIPHE Research Unity since 2021 (2020 trial period included). The laboratory was initially created in 2017 with the status of an emerging team. The dynamism and strong scientific production of the team made it possible to establish the scientific project culminating in a recognized research unit (UR DIPHE) from the University of Lyon 2. The unit specializes in understanding the functional principles of typical and atypical development from an early age. Quentin Hallez (the scientific coordinator) already has experience in funded research projects having participated during his doctoral thesis (PhD defence July 2019) in the European Commission's "Research and Innovation Framework" Program (H2020-FETPROACT-2014, n°641100), *Mind and Time: Investigation of the Temporal Traits of Human-Machine Convergence* (TIMESTORM). Since then, Quentin Hallez has become a specialist in the field of development, particularly regarding the development of cognitive abilities and time perception, modelling, and artificial neural networks. Last year he became a member of the Well- being at School Observatory. This observatory not only allows him to make his research more visible, but also enables him to be in contact with leading national education figures. Highly motivated, he has a strong scientific production record for a researcher at this early stage of his academic career with several first-author publications in highly-ranked journals in developmental psychology (e.g., Scientific Reports (x2), Journal of Experimental Child Psychology (x 2), the Journal of Cognitive Psychology, Infant and Child Development…). The coordination of the PI from WP1 to WP5 would result in taking care of the majority of the administrative procedures (ethical applications, application forms for authorization for research studies in schools), design the studies with researchers, programming the studies in python language, follow and train non-permanent staff, help the team with data collection, realization of inferential statistics (or Bayesian if needed), design and programming of neural networks with associated researchers, disseminate the results through hard-hitting written or oral communications.

Table 3. **Involvement of the scientific coordinator (Quentin Hallez) in on-going projects**

Name of the researcher	Person. month	Call, funding agency, grant allocated	Project's title	Name of the scientific coordinator	Start - End
Quentin Hallez	7.2	ANR-AAPG2021-PRC	ALIMNUM: ALIMentation et NUMérique	Pascale Ezan, (Normandie University)	2021-2025

Consortium. Anna Rita Galiano (permanent lecturer, HDR, head of DIPHE laboratory; Lyon Univ.), is an expert in differential psychology and specifically regarding sensory issued (WP3,4). Nicolas Baltenneck's (permanent lecturer. Dev. Psy.; Lyon Univ.) research on spatial representation and spatial actions in blind subjectswill be of great help in our project (WP1 & 4). Dannyelle Valente (permanent lecturer. Dev. Psy.; Lyon Univ. & Geneva [Switzerland].) is also an expert on the topic of blind children, who will be able to help the team to recruit early blind children (WP3,4). Florie Monier (Orthoptist. Therapist & permanent lecturer. Faculté de Médecine, Clermont-Ferrand) has published significant prior research on the topic of time perception and motor skills (Developmental Science, Child Neuropsychology) (WP2,4). Joanna Lucenet's (permanent lecturer. Dev. Psy. Univ. Bordeaux) work focuses on the development of executive functions (WP1,2). Royce Anders (permanent lecturer. Cognitive Science; University of Lumière Lyon 2) has many articles related to Bayesian statistics to his credit and has recently submitted articles on neural network modelling (WP2,5). Fuat Balci, (non-permanent external researcher, Cognitive Psychology) is a recognize expert in the field of time perception. Although he never worked on a children population, his theoretical and modeling knowledge will be an excellent support for our project. As was previously explained, to complement the team, non-permanent members (research assistants and a PhD student) will also be recruited to join this project.

2.2. Implemented and requested resources to reach the objectives

Partner: DIPHE lab (Développement, Individu, Processus, Handicap et Education)

Staff expenses. As was already set out in the previous sections, it will be necessary to hire several non-permanent team members, including one PhD student with a background in cognitive and developmental psychology. Part of his/her work will also be dedicated to manuscript preparation and dissemination. The PhD student will be co-directed by Quentin Hallez and directed by one of his/her colleagues at the DIPHE laboratory, who may be an outsider (e.g., Jean-Yves Baudouin as director) or an insider (e.g., Anna-Rita Galiano) in relation to this ANR project (according to the preferences of the ANR-JCJC). The cost for a 3-year PhD student is 105 000€. Research assistants, who will be directed by Quentin Hallez, will also be needed to recruit and run experiments with visually impaired children. The cost for an 8-month research assistant is 21 200€. Finally and in order to reach the research objectives in the planned time, a teaching release is required, at a cost of 23 040€ (i.e., 96 hours over the total duration of the project).

Table 4. **Requested means by item of expenditure.**

		Partner – DIPHE UR
Staff expenses		151.200
Instruments and material costs (including scientific consumables)		5.686
Building and ground costs		/
Outsourcing / subcontracting		7.300
General and administrative costs & other operating expenses	Conferences and meetings	18.600
	Administrative costs	24.677
Total requested funding		**207 462 €**

Staff expenses. As was already set out in the previous sections, it will be necessary to hire several non-permanent team members, including one PhD student with a background in cognitive and developmental psychology. Part of his/her work will also be dedicated to manuscript preparation and dissemination. The PhD student will be co-directed by Quentin Hallez and directed by one of his/her colleagues at the DIPHE laboratory, who may be an outsider (Jean-Yves Beaudouin as director) or an insider (Anna-Rita Galiano) in relation to this ANR project (according to the preferences of the ANR-JCJC). The cost for a 3-year PhD student is **120 000€.** In addition, a 8-months research assistant, who will be directed by Quentin Hallez, will also be needed in order to help for the recruitment and the handover and of the experiments in WP1. The cost for a 8-month research assistant is **21 200€.** As expressed by the expert within the final pre-proposal report "sufficient availability must be ensured to coordinate all aspects of the project". In order to do so, a teaching release is also required, especially for the first year of the project in order for the PI to launch the various projects, at a cost of **10 000€** (i.e., 64 hours for the first year).

[Total Staff expenses = 120 000 + 21 200 + 10 000 = 151 200 €].

Instruments and material costs. This project will benefit from the licence (i.e., SPSS) and neuropsychological tests (i.e., 5th version of the Weschler Intelligent Scale for Children) already available at DIPHE Lab. Nevertheless, some purchases are to be expected.

An amount of **3700€** is thus planned for computer equipment. Indeed, the purchase of a laptop with a high capacity (1700€) will be of need to perform the modelling of WP5, along with a laptop dedicated for the PhD student (1000€) and a laptop dedicated to handovers in schools (1000€).

Also, an amount of **932€** will be dedicated to test purchased. The latter including the "Test of Everyday Attention for Children" (TEACh) (650€); and the corsi board (75€)].

In addition, an amount of **905€** is required to build the different elements described in the methodology sections. 719€ will be allocated for the device of Study 1c [details; 11x laser cross (168€), 11x Speakers (45€), laser pointer (10€), 4k Camera (139€), projection canvas (150€), other mechanical and electrical elements needed for the construction (207€)] as well as 185€ for the auditive spatial bisection task used for WP1 & 3 (Tascam microphone 125€ ; 2x headphones = 60€).

Finally, we plan **150€** for the purchase of stickers for the participation of children.

[Total instruments and material costs = 3 700 + 932 + 719 + 185 + 150 = 5 686€].

Building and ground costs. Non applicable

Outsourcing / subcontracting. This includes publication to open access journal (for example, for scientific report, the cost is 2334€) and traduction fees, cost: **7300€**

[Total outsourcing / subcontracting = 7 300€].

General and administrative costs & other operating expenses. This includes international conferences (around 3 nights/conference – 1 500€ x 3 years x 2 members – PI, PhD student): cost: **9 000€**, national conferences (around 2 nights/conference – 600€ x 3 years x 2 members, PI, PhD student): cost: **3 600€**, as well as the cost related to team meetings in Lyon for the French researchers: 4 years x 2 days x 3 members = **6 000€** (3 members are outside of Lyon) and **24 677€** for administrative cost (13,5%).

[Total Gen. & adm. costs / other operating expenses = 9 000 + 3 600 + 6 000 + 24 677 = 43 277€].

3. Impact and benefits of the project

The project's multifactorial contribution. The objective of CES28 "Cognition, Comportement, Langage" is to gain "better understanding of the human cognition and thought (skills and capacities of the brain; psychology)" (AAPG, 2023, p43). Because of its **theoretical contributions**, this timely research will be in line with these aims, as it will greatly contribute to our fundamental understanding of how humans process time, or even more generally, how humans deal with continuous quantities. There is currently a debate about the nature of interference between spatial and temporal processing. According to the asymmetry hypothesis, spatial processing interferes with temporal processing, but the converse is not true. According to the symmetry hypothesis, the processing of space and time mutually interfere with each other. Although these two hypotheses corroborate the idea of an influence of space on temporal processing, no study has yet systematically analysed the origin of this interference with a view to modelling it and creating a time processing model which takes spatial information into account. Nonetheless, our ambition does not stop there. By modelling the one-to-one interferences between time and space through childhood among a population with and without visual impairments, we will address unresolved and ongoing theoretical debates about the nature of perceptions of time-space relations.

This program will also make **social contributions** since we will, for the first time, analyse the development of temporal skills in visually impaired children. If it is observed that visually impaired children present delays in their temporal representations which are equivalent to the delay already observed in their spatial representations, then new arrangements reflecting integration and adaptation will have to be put in place by practitioners, teachers working with this population, and even by municipalities. To deal with these social repercussions, we can count on our numerous collaborators (previously presented) made up of specialized structures and associations, who will be able to convey our message and disseminate our results.

To a lesser extent this project may also provide a **clinical contribution**. Note that this will not be a direct implication of our timely research project, but rather a possible future outcome. Indeed, since we proposed a mediation axis in our program (WP4), we may provide new ways to improve space or time perceptions. These results could be important, not only for visually impaired children, but also for children with delays/abnormalities in their spatial and temporal representations. For example, for individuals with visuospatial dyspraxia, a disorder affecting organization in space such as two-dimensional activities.

The elements covered in this program will also have a **Pedagogical contribution**. Indeed, whatever the results obtained within the framework of our various results, they will have implications in the school field, in particular with regard to educational programs, since they will imply an order of learning between time and space. If the symmetrical hypothesis is valid, then the learning of time and space must take place at the same time. Conversely, if the asymmetry hypothesis prevails, it is first necessary to construct for the child a solid representation of space before being able to construct any temporal representation.

Finally, this project also contains a **Technical contribution** in the field of Artificial Intelligence. There is no doubt that time perception is not an optional extra; rather, it is a necessity for the development of truly autonomous, cognitive machines. The desire to create social robots capable of synchronizing and adapting to humans in increasingly varied contexts requires endowing artificial agents with temporal cognition similar to that of humans. Our research will therefore not only have consequences for the encoding of time and space in the machine, but will also make it possible to understand how space and time interfere with each other, and how robots must adapt to the human(s) they are with to achieve symbiotic interactions. This element will be at the center of a future call for projects for the "Starting Grant" of the European Research Council.

Strategy for valorisation and science communication. The outcomes provided by this project will be published in reputable international peer-reviewed journals (e.g., Developmental Science, Journal of Experimental Child Psychology, Cognition, Trends in Cognitive Science) and disseminated at National and International Conferences (Réseau Interuniversitaire de PSYchologie du DEVeloppement de l'Education; European Society for Cognitive Psychology; Cognitive Development Society). Thanks to the ongoing connections of each of the consortium members, the findings will also be spread through several additional channels (e.g., local radio, associations…). This is fortunate, as our intention is to extend our results to a wider population. To support this ambition, we also plan to participate in cultural and scientific meetings (e.g., Fête de la Science, Semaine du Cerveau).

In addition, through his status of member of the Observatory of Well-being at School, Quentin Hallez will promote the work carried out by the team by publishing a summary of the results on this web page. This will enhance the visibility of our research. Finally, out of a desire for transparency, four Massive Open Online Courses (MOOC) will be carried out (at the end of each school year). These free access courses will be intended for teachers, staff attached to the Departmental Services of National Education, health professionals (orthoptists, psychologists, and so on), members of the associations with which we collaborate as well as parents. The idea is to provide a meeting space between researchers and the public, to popularize our results, to show the direct consequences through practical examples, and at the same time to advance research and confidence in science by encouraging open and transparent dialogues between researchers and the public. Quentin Hallez, coordinator of the project, already participated in the organization of similar activities.

Responsibility / development. The DIPHE laboratory to which Quentin Hallez is attached now has two major themes that are not being dealt with independently of one another. Funding for this project would allow the complete reorganization of the research axes of the coordinator's laboratory, with the position of head of a research axis taken by Quentin Hallez. Carrying out a joint project with the members of his laboratory will allow the coordinator not only to integrate his new research team, but also to help his emerging laboratory to find a research identity. Finally, this funding would constitute a real springboard for a young researcher who aspires to respond, following this project, to the call for projects funded by the "Starting Grant" of the European Research Council.

4. References (The references for which on or more of the authors are involved in the project are in bold).

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