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Review Article

Development and influencing factors of young children's temporal cognition: A systematic review

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Abstract: This study adheres to the PRISMA statement, synthesizes 16 empirical studies published between 2015 and 2025, and explores the developmental rules and influencing mechanisms of temporal cognition in children aged 3 to 10 years. The results show that children's temporal cognition is a transformative process, shifting from dependence on concrete cues to abstract and independent representation, under the combined influence of biological maturation and the acquired environment. The dynamic synergy between executive function and the internal clock system in the temporal cognitive mechanism serves as the physiological basis for its development; emotions, effortful control, and early literacy skills are key influencing factors, with their effects exhibiting individual differences and situational dependence. In terms of mental representation, younger children (aged 4-6 years) rely on event density or emotions to judge time, while older children (aged 8-9 years) ultimately achieve abstract thinking and independent judgment of time itself by constructing a stable horizontal mental timeline. This study refines the theory of children's temporal cognition and provides some references for preschool education practice. Meanwhile, this study also has limitations, such as insufficient sample representativeness and constraints imposed by the cross-sectional design, and future research needs to be further deepened.

Keywords: Temporal cognition, Time cognition, Child development, Internal clock system, Early literacy, Preschool education, Systematic review, PRISMA

Introduction

Time, as a fundamental aspect of material existence and movement, is a core dimension of human consciousness and practical activity. All stimuli and activities have temporal boundaries, and the perception of time is a universal, continuous experience. (Matthews & Meck, 2016) The objective importance of time determines the significance of temporal cognition. Temporal cognition refers to an individual's ability to perceive, understand, and apply objective time (Timmerman et al., 2024). During individual development, early childhood is a critical period for temporal cognition, marking the transition from the perception of primitive physiological rhythms to a complex, symbolic system of mental representation. This study defines young children as 3-10 years old (Droit-Volet & Wearden, 2001), consistent with international studies.

Development during this period not only affects young children's logical thinking, memory, and language abilities, but also profoundly shapes a range of competencies, such as social adaptation and self-regulation.

At this stage, young children's temporal cognitive abilities

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undergo a series of qualitative changes. Their perception of time develops from passive associations between stimuli and responses formed through unconscious physiological conditioned reflexes in early life to the gradual formation of abstract temporal concepts capable of mental representation—for example, using temporal language such as "before" and "after" to represent event sequences mentally; from focusing primarily on the present to being able to recall the past and anticipate the future; from vague perceptions of temporal duration to relatively accurate judgment and grasp of time intervals. This seemingly natural transformation is underpinned by the complex interplay and coordinated development of multiple cognitive abilities, including perception, memory, and language.

In recent years, with increasing social emphasis on early education and the advancement of research into young children's cognitive development, temporal cognition in early childhood has gradually become a focus in psychology and education. Regarding research content, existing studies mainly focus on three primary directions: First, research on basic temporal concepts includes the identification of time points, discrimination of temporal order, initial cognition and understanding of temporal words (Tillman & Barner, 2015), and young children's ability to perceive and judge the duration of different activities (McCormack, 2015; Haggai, 2014; Ayhan et al., 2015). Studies have shown that these abilities develop rapidly during the preschool period and are correlated with other cognitive domains (Arterberry & Albright, 2020); Second, research on temporal cognitive strategies aim to reveal how young children transition from relying on external, concrete cues (e.g, "when the sun sets, it is evening") to using internal, abstract frames of reference to represent time. For example, studies have found that young children spontaneously form a mental timeline, linearly arranging time in space – especially horizontal space – and that this ability develops in parallel with age and space and numbers (Droit Volet al., 2015) (Droit-Volet et al., 2015). Third, research examines the key factors influencing the development of young children's temporal cognition. Among these, cognitive control (such as inhibition and switching) has been proven to be a core mechanism supporting the accuracy of temporal judgment (Hallez, 2020; Arterberry & Albright, 2020); the valence and arousal of emotions affect individuals' subjective experience of time passage (Martinelli & Droit-Volet, 2023; Qu F et al., 2021); understanding temporal language provides a symbolic tool for constructing abstract temporal concepts (Tillman & Barner, 2015); in addition, sociocultural factors such as family time structure and socioeconomic status (SES) also influence young children's temporal cognitive development through resources and the environment (Segretin et al., 2024). Regarding research methods, most existing studies use standardized experimental tasks and generally employ cross-sectional designs to examine the developmental characteristics of children's temporal cognition. For instance, researchers have used temporal bisection (judge target duration against short/long standards; (Hallez, 2020; Mioni et al., 2018) and temporal reproduction to investigate the development of young children's duration perception (Segretin et al., 2024); meanwhile, some researchers have used more ecologically valid tools, such as mental timeline tasks, to reveal young children's spatial representation of temporal order. (Mioni et al., 2018) In summary, these studies provide strong evidence for the quantitative analysis of the intrinsic developmental mechanisms of young children's temporal cognition through controlled experimental designs.

Overall, existing research on young children's temporal cognition has accumulated relatively substantial findings. However, studies in this field remain fragmented and lack systematic integration, limiting our overall understanding of the developmental mechanisms underlying young children's temporal cognition and underscoring the need for a systematic review.

Firstly, existing research findings are contradictory on some key issues, requiring a systematic evaluation to clarify these controversies. For example, regarding the relationship between cognitive control and temporal perception, classic theories emphasize the core role of attentional resource allocation (Zakay & Block, 2004). However, recent studies have indicated that age-related changes in inhibitory control and cognitive switching are key mediating variables linking age to improvements in temporal perception, while working memory or general attention has no significant predictive effect (Hallez, 2020; Arterberry & Albright, 2020). Secondly, existing studies exhibit considerable heterogeneity in research methods. For example, in terms of measurement tools, different studies adopt various paradigms, ranging from precise temporal bisection and temporal reproduction to more ecologically valid mental timeline tasks (Hallez,2020; Segretin et al., 2024; Droit-Volet & Coull, 2015). This inconsistency makes it difficult to compare and integrate research conclusions directly; in addition, in terms of sample selection, research groups are mainly concentrated on children over 3 years old, with relatively few studies on infants under 3 years old; meanwhile, although individual studies have begun to focus on the regulatory role of socioeconomic status (SES) in temporal cognition (Segretin), samples from low-SES groups and non-Western cultural backgrounds are relatively scarce, limiting the generalizability of conclusions. Finally, current research mostly remains at the level of describing intrinsic mechanisms, and there is a significant disconnect between research findings and practice, hindering the development of actionable educational intervention strategies. For example, Segretin found that effortful control is associated with the accuracy of judging specific durations. Autry et al. (2020) discovered that the development of the mental timeline is closely linked to early literacy skills. At the same time, age itself no longer has a significant predictive effect, indicating that cultural acquisition is a more explanatory factor in young children's temporal cognitive representation than psychological maturation. However, these valuable research findings have not been effectively transformed into educational tools that preschool educators or parents can understand and directly apply.

Based on these reasons, this study will follow the PRISMA statement to conduct a systematic review of 16 selected high-quality empirical studies, aiming to identify the key factors influencing the development of young children's temporal cognition and their interaction mechanisms. This will enable the construction a more comprehensive theoretical model and provide references for future preschool education practice and research.

At the early stage of the systematic review, and drawing on previous research, this study formulated the core research questions as follows:

1. What are the core factors affecting the development of young children's temporal cognitive abilities?
2. Through what mediating or moderating mechanisms do these factors function, and what is their interaction mode?

Materials and methods

Following the PRISMA guidelines, this systematic review was conducted in three stages: study identification, literature search, and screening and evaluation. Based on the research theme and objectives, we searched for studies on the factors influencing young children's temporal cognition.

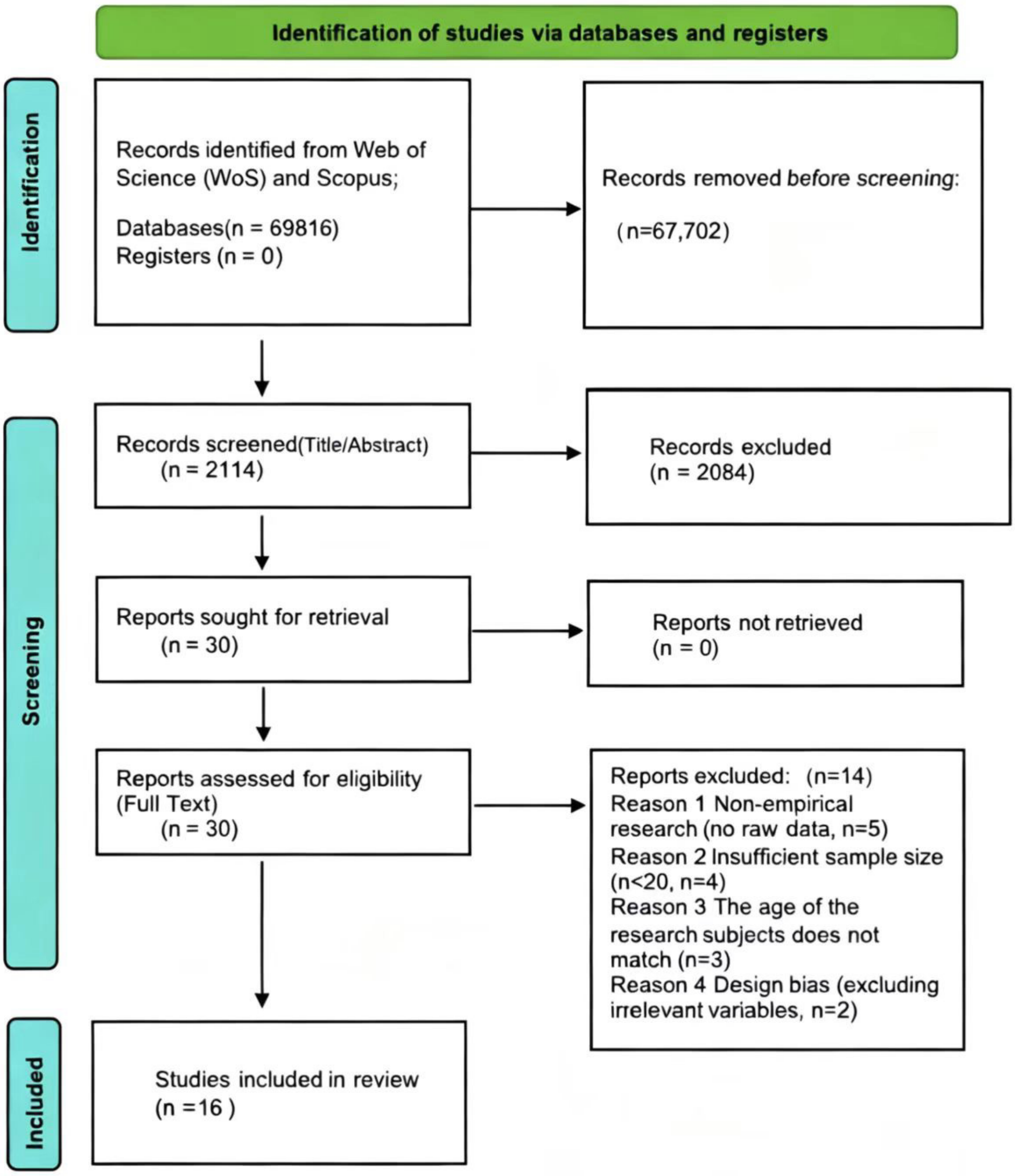

Figure 1. PRISMA 2020, Literature retrieval flowchart

Selected literature

The systematic review method helps integrate supporting information in key areas, thereby exploring the overall research results of the research topic and contributing to the improvement of research on specific research questions. Guided by the PRISMA standards, this systematic review searched and identified literature in extensive and effective databases.

Systematic literature exploring scheme

Per PRISMA, the search included three stages. No initial database filters were used (to avoid missing studies); manual screening was limited to target disciplines/ languages/types. To ensure the effectiveness of keywords, we adopted Boolean operations, combining keywords with logical operators (such as AND, OR, NOT) to form precise search expressions, and conducted the literature search in the Web of Science (WoS) and Scopus databases using these expressions. The relevant search expressions are as follows:

("early child*" OR "young child*" OR "preschool child*" OR "preschool*" OR "kindergarten child* ") AND ("time/temporal language" OR "time/temporal word*" OR "timeline*" OR "time/temporal terms" OR "time/temporal order" OR "time/temporal sequence*" OR "time/temporal process*" OR "time/temporal estimation*" OR "time/ temporal distance" OR "duration*" OR "time/temporal judgement*" OR "time/temporal perception*" OR "time/ temporal aware*" OR "time/temporal concept*" OR "sense of time/temporal" OR "time/temporal cognition" OR "time/ temporal reasoning" OR "time/temporal understanding" OR "time/temporal orientation").

Screening phase

Using the above keywords, two researchers retrieved 69,816 articles from the Web of Science (WoS) and Scopus databases. To ensure the scientific validity and high relevance of the included studies to the research theme, the researchers formulated inclusion and exclusion criteria for systematic screening.

Only journal articles were included in this review. Reviews, conference abstracts, dissertations, and book chapters were excluded to ensure all analyses were based on peer-reviewed original studies. To keep the review timely, the search focused on studies published between 2015 and 2025. Only English-language publications were included, reflecting the research team's language proficiency and English's role as the main medium for international academic exchange in this field. This decision ensured a clear understanding of the literature. The review focused on education, psychology, and cognitive science to identify studies most relevant to young children's temporal cognition, while excluding less relevant areas.

After applying these criteria and removing duplicate records, 2,114 articles proceeded to the title and abstract screening stage. Two reviewers independently screened the titles and abstracts using the defined inclusion and exclusion criteria. They discussed and resolved any differences through consensus. If agreement could not be reached, a third independent reviewer helped make the final decision. After this process, 30 articles were identified as meeting the inclusion criteria and advanced to the full-text review stage.

Table 1. Inclusion and Exclusion Criteria

Screening requirements	Include	Exclude
Language	English	Other Languages
Document Type	Journal Paper	Overview, conference abstract, thesis, book chapter
Time Range	2015-2025	2014 and earlier
Subject Category	Education, Psychology, and Cognitive Science	Other fields

Eligibility

We re-examined articles with controversial content to determine if they met the criteria. At this stage, the full texts of the studies were carefully read. Only articles meeting the following criteria were selected for further research: (1) The research theme directly focuses on core aspects of temporal cognition, such as temporal perception, temporal estimation, temporal memory, or temporal judgment. It provides at least relevant analysis, qualitative evidence, etc., rather than merely mentioning without empirical data support. (2) The research subjects are all typically developing children aged 3-10 years. (3) The research type is quantitative, qualitative, or mixed-method empirical research, rather than literature without original data, insufficient sample size ($n < 20$), or with obvious design bias (e.g., uncontrolled extraneous variables).

Quality assessment

To ensure the methodological quality of the selected studies and reduce potential bias, this review uses MMAT 2018 ($\geq 4/5$ = high quality), with independent ratings by two reviewers, and resolves disagreements through consensus. Two reviewers independently evaluated each study in strict accordance with the MMAT guidelines. The assessment followed three main steps: first, the screening questions were applied to clarify the research questions and to examine the relevance of the collected data, ensuring that each study directly addressed issues related to temporal cognition; second, the methodological rigor of the studies was assessed, including the representativeness of the samples and the reliability and validity of the measurement instruments; third, the appropriateness of the statistical methods in relation to the research design was examined to ensure the soundness of the data analysis. Any disagreements between the two reviewers were resolved through discussion and consensus, and when necessary, a third reviewer was consulted to make the final decision.

Based on this procedure, 16 studies met the MMAT criteria for high methodological quality (score ≥ 4/5), showed no substantial risk of bias, and were therefore included in the final systematic review.

Data extraction and analysis

A systematic analysis was conducted on 16 studies. Two researchers independently extracted data (Cohen’s kappa = 0.91) and screened the literature (kappa = 0.87); disagreements were resolved by a third researcher. Data accuracy was verified via cross-checking. Data extraction followed the standard procedures of the Cochrane Consumers and Communication Review Group, covering content aligned with the dimensions of the "Description of Reviewed Studies" table: first, basic research information such as author, publication year, sample size, age distribution, gender ratio (if reported), and research country; second, research method details including research design, experimental tasks, measurement tools, stimulus parameters, and analytical approaches; third, core research elements such as research purpose, key independent variables, and time-related dependent variables; fourth, research results including key statistics, effect sizes, core conclusions, and the direction and intensity of variable effects.

Research results

Basic characteristics of included studies

The literature screening strictly followed the PRISMA process: after initially identifying 2,114 studies, 30 articles entered the subsequent full-text intensive review stage after title and abstract review. Finally, after full-text intensive reading, 16 studies fully met the preset inclusion criteria. These studies include: Hallez et al. (2019), Hallez (2020), Tillman & Barner (2015), Hallez & Droit-Volet (2017), Droit-Volet (2017), Arterberry & Albright (2020), Droit-Volet & Coull (2015), Mioni et al. (2018), Qu et al. (2021), Martinelli & Droit-Volet (2023), Hallez & Droit-Volet (2018), Stojić et al. (2023), Segretin et al. (2024), Sener & Starr (2025), Autry et al. (2020), DeNigris & Brooks (2018), etc.

All studies were published in English, with research regions mainly concentrated in European and American countries, and some studies from China. The research samples range in age from 3 to 10 years, with sample sizes of 30 to 249, all of which are typically developing children without special groups. These studies were published between 2015 and 2025, focusing explicitly on the following aspects:

1. Core cognitive mechanisms of children's temporal cognitive development, including the regulatory role of executive function (inhibitory control, cognitive switching), developmental characteristics of the internal clock system (pacemaker frequency, switch regulation efficiency), and formation mechanisms and stage characteristics of the mental timeline;
2. Modulatory effects of emotions, situations, and individual differences, including the dynamic impact of emotion type and presentation order, the interference effect of others' physical states, the role of spatial cues, digital cues, and interfering stimuli on temporal judgment, as well as gender differences, the interaction between socioeconomic status (SES) and temperament, and the influence of cultural situational factors such as early literacy skills;
3. Development and transformation of representational styles, including the formation stage of the "mental timeline", the developmental trajectory of understanding the relative order and absolute duration of temporal words, age characteristics of nonverbal gesture expression (direction proportion, amplitude), cognitive development of the association between time, speed, and space, and the shaping of temporal cognitive representation by language ability.

Regarding the age of research samples, five studies focused on young children aged 3 to 5 years, mainly investigating the relationship between early temporal perception and attention/inhibitory ability, the influence of emotions, others' states, and event density, the interaction between temperament, SES, and early literacy skills, as well as the understanding of simple temporal words and nonverbal gesture expression; 5 studies covered children aged 5 to 7 years, focusing on analyzing the mechanism of executive function and temporal cognition, the linear development of the mental timeline, and temporal memory mechanisms; 4 studies extended to children aged 6-10 years, exploring the formation of the "mental timeline", the association between spatial/digital cues and temporal judgment, the age interaction between language ability and temporal cognition, as well as general temporal knowledge and calendar flexibility, with some studies including adult samples for comparative analysis.

In terms of research design, all 16 studies are experimental; task types include temporal bisection task, temporal reproduction task, mental timeline task, tapping frequency task, event temporal order memory task, video duration comparison task, analog scale judgment task, temporal marking and month order task, etc., with measurement content involving multiple dimensions such as temporal perception, temporal memory, temporal estimation and order judgment, reaction time, and gesture direction and amplitude.

Development and nfluencing factors of children's temporal cognition

Core cognitive mechanisms of children's temporal cognitive development

The maturation of children's temporal cognition is not the development of a single cognitive ability, but rather the coordinated development of the brain's executive function and internal clock system. Executive function actively processes temporal information by coordinating the allocation of cognitive resources, while the internal clock system, as its physiological basis, determines the accuracy and stability of temporal perception. Together, these systems promote the transformation of children's temporal cognition from "passive dependence on external stimuli" to "active integration of objective temporal information".

Regulatory role of executive function

Executive function, mainly inhibitory control and cognitive switching, is a key predictive variable affecting the accuracy of temporal cognition, with inhibitory control and cognitive switching influencing the processes of temporal perception and temporal memory, respectively.

Inhibitory control is the ability to resist interference and inhibit impulsive responses. It is mainly responsible for temporal perception, i.e., judging how much time has passed in the present. Hallez's study clearly revealed the core role of inhibitory control in temporal perception. In this study, researchers used a complex pattern of non-temporal distractors to distract children's attention. The results showed that 5-8-year-old children underestimated time, a phenomenon called the "time contraction" effect, and that this effect weakened with age. The study showed that not all cognitive abilities affect the time contraction effect; only inhibitory control ability is the fundamental reason for the performance differences among children of different ages. In addition, the study found that working memory and selective attention had no significant predictive effects on the time contraction effect ($ps > 0.15$), further highlighting the specificity of inhibitory control. This proves that the quality of attention control is more important than the amount of attention resources. This view supports the "dual classification of attention interference" perspective, i.e., the attention control level, as represented by inhibitory control, rather than attention resource capacity, is a more core factor in the development of children's temporal perception.

Cognitive switching is the ability to switch between tasks or thinking modes flexibly. It is mainly responsible for temporal memory, i.e., remembering and judging the sequence of events. Arterberry and Albright's study highlighted the importance of cognitive switching in temporal memory. In this study, researchers asked young children to recall the sequence of events in a story. To sort them correctly, young children needed to flexibly switch between thinking about different events in the brain. The study found that, after controlling for age, only cognitive switching ability significantly predicted the performance of 3- to 6-year-old children in the story temporal order task. In contrast, inhibitory control and temporal language understanding did not. This shows the unique role of cognitive switching in temporal memory, indicating that the memory and judgment of event sequences depend more on this flexible, general thinking ability than on time-specific abilities.

Developmental characteristics of the internal clock system

The internal clock system is a hypothetical cognitive-biological model based on neurophysiological structures that explains humans' ability to perceive, estimate, and judge short time intervals (e.g., milliseconds to minutes). The core function of this system is to generate subjective temporal experience by producing, accumulating, and interpreting neural pulse signals. It is not a specific organ but a distributed network spanning multiple brain regions. Its classic model includes three core components: a pacemaker, an attention switch, and an accumulator.

The physiological maturation of the internal clock system underlies the development of temporal cognition, and its core changes are reflected in increased pacemaker frequency and enhanced switch regulation efficiency. Droit-Volet's study provided direct evidence for the hypothesis that children's internal clock is slower. Researchers used auditory clicks of different frequencies (8Hz and 20Hz) to externally "drive" the internal clocks of children and adults. The results showed that 5-year-old children perceived time as prolonged during slow clicks (8Hz). However, this effect weakened or even reversed under fast clicks (20Hz). Adults showed a more substantial impact under fast clicks (20Hz). This indicates that the children's internal clock itself has a slow rhythm. Slow clicks match its own slow rhythm, so it can effectively "synchronize", accumulate many pulses, and make time feel long. Fast clicks exceed the synchronization capacity of children's internal clocks, leading to desynchronization, reduced pulse-accumulation efficiency, and, in turn, making time feel short again. Adults' internal clocks have a fast rhythm so that they can keep up with faster clicks. The study also found that children with better attention and working memory showed a weaker effect. This indicates that higher cognitive abilities can, in turn, regulate and optimize the operation of this physiological clock, and this regulatory ability also increases with age.

Table 2. Description of reviewed studies

Serial Number	Author (Year)	Country	Research Purpose	Participants	Methods	Design	Key Independent Variables	Time-Related Dependent Variables	Key Findings
1	Hallez et al. (2019)	France / Netherlands / UK	To explore how temporal context (duration distribution) affects time reproduction in children and adults, and to analyze age differences in central tendency effects	80 children aged 5–7 (24 aged 5, 31 aged 6, 25 aged 7); 33 adults (mean age 20.43)	1. Behavioral experiment: Ready-set-go time reproduction task; 2. Statistical analysis: LMM, Bayesian, CV, post hoc	Within-subjects: global context (short/long), local context (recent trials); Between-subjects: age group; 2 contexts × 4 blocks × 20 trials	1. Context: short (0.5–0.9s) vs long (0.9–1.3s) duration distributions; 2. Local context: previous 1–2 objective durations, previous 1–7 subjective reproductions; 3. Age: 5, 6, 7, adult	1. Reproduced duration; 2. Stability of time representation; 3. Central tendency strength; 4. Local context effect	Global context: 0.9s overestimated in long context (significant in 5-year-olds and adults); Local context: 5-year-olds rely more on previous objective/subjective durations; Age negatively related to variability; All ages influenced by previous 1–2 trials
2	Hallez (2020)	France	To examine the effect of non-temporal distractors on time perception and test whether inhibition mediates time contraction	95 children aged 5–8 (20 aged 5, 25 aged 6, 24 aged 7, 26 aged 8); 25 adults (mean age 20.70)	1. Visual bisection task; 2. Neuropsychological tests: Corsi, TEA-Ch, NEPSY; 3. ANOVA, mediation (Bootstrap)	Within-subjects: distractor (present/absent), duration range (short/long); Between-subjects: age group	1. Distractor: 4 cm rose shape, 40 ms; 2. Cognitive abilities: inhibition (NEPSY), selective attention (TEA-Ch); 3. Duration ranges: 400/1500 ms, 600/2400 ms	1. Bisection point (BP); 2. Weber ratio (WR); 3. Time contraction (BP shift due to distractor)	Distractor shifted BP rightward (time contraction) strongest in 5-year-olds (235.93 ms); Inhibition mediated age effect (indirect B=0.19, 95% CI [0.08,0.35]); Other cognitive variables non-significant
3	Tillman & Barner (2015)	USA	To investigate the developmental trajectory of duration word acquisition (e.g., second/minute/hour) and distinguish between relative and absolute understanding	249 children aged 3–7 across 3 experiments; 36 adults (mean age 20.7) in Exp 3	Forced-choice tasks, number-line and timeline tasks; LMM analysis	Within-subjects: word pairs, task type; Between-subjects: age group	1. Duration words: second, minute, hour, day, week, month, year; 2. Task types: relative order, number-time integration, timeline placement	1. Relative order accuracy; 2. Number-time integration accuracy; 3. Timeline estimation error	4-year-olds: 57% correct in order task; 7-year-olds: 82%; Adults: 95%; Absolute understanding improved significantly by age 6; No difference across word types
4	Hallez & Droit-Volet (2017)	France	To clarify the cognitive mechanisms of time contraction in dual-task conditions in children, focusing on attention, memory, and processing speed	57 children aged 5–7 (22 aged 5, 15 aged 6, 14 aged 7)	1. Single vs dual-task time reproduction; 2. Neuropsych tests: TEA-Ch, Corsi, WISC; 3. ANOVA, regression	Within-subjects: task type (single/dual), target duration (6s/12s); Between-subjects: age group	1. Task type; 2. Cognitive abilities: selective attention, working memory, processing speed; 3. Target durations: 6s, 12s	1. Reproduced duration and contraction; 2. Standard deviation; 3. Non-temporal task accuracy	Dual-task caused time contraction, strongest in 5-year-olds (9949 ms at 6s); Selective attention best predictor (β=0.445, p=0.014); Shared attentional resources between tasks

Serial Number	Author (Year)	Country	Research Purpose	Participants	Methods	Design	Key Independent Variables	Time-Related Dependent Variables	Key Findings
5	Droit-Volet (2017)	France	To test the “slower internal clock” hypothesis in children using auditory clicks at different frequencies	38 children aged 5, 37 aged 8; 40 adults (mean age 22.67)	1. Auditory clicks + visual bisection task; 2. Tests: digit span, TEA-Ch; 3. ANOVA, correlation	Within-subjects: click condition (none/8Hz/20Hz), duration range (short/long); Between-subjects: age group	1. Click condition: 5s tones at 8Hz/20Hz; 2. Cognitive: working memory, selective attention; 3. Duration ranges: 200/800 ms, 400/1600 ms	1. Bisection point (BP); 2. Time expansion (BP shift); 3. Frequency effect	Children showed strongest expansion at 8Hz (BP leftward 80–100 ms); Adults at 20Hz (120–150 ms); 5-year-olds showed reversal at 20Hz (BP rightward 40 ms); Working memory correlated with frequency effect (r=0.26)
6	Arterberry & Albright (2020)	USA	To explore factors influencing children's memory for the temporal order of story events, focusing on executive function and temporal language	40 children aged 3–6 (young: 52.35 months; older: 69.25 months)	1. Story reading + timeline task + yes/no recognition; 2. EF tests: Day-Night Stroop, DCCS; 3. ANOVA, regression	Within-subjects: task type; Between-subjects: age group	1. Age group; 2. Executive function: cognitive shifting (DCCS), inhibition (Stroop); 3. Task type: timeline, before/after comprehension, detail recognition	1. Temporal order accuracy; 2. Before/after comprehension; 3. Detailed memory accuracy	Older children: 72% correct in temporal order; Younger: 51%; Cognitive shifting predicted temporal memory (β=0.40, p<0.05); Detail memory better than temporal memory
7	Droit-Volet & Coull (2015)	France	To investigate the development of the mental timeline in children and test interference from spatial and numerical symbols	40 aged 5, 43 aged 8, 40 aged 10, 40 adults	1. Spatial/numerical cues + visual bisection task; 2. ANOVA, post-hoc	Within-subjects: cue type (spatial/numerical), duration range; Between-subjects: age group	1. Cue type: left/right arrows, digits 1/9; 2. Age groups: 3. Duration ranges: 200/800 ms, 400/1600 ms	1. Bisection judgment; 2. Cue interference effect; 3. Spatial-time / number-time association	10-year-olds and adults: right arrow and digit “9” shifted BP leftward (longer perception); 5–8-year-olds showed no effect; Numerical cues stronger than spatial (F=4.87, p=0.03)
8	Mioni et al. (2018)	Italy / Canada / Israel	To examine how symbolic speed (fast/slow) and motion (moving/static) affect time reproduction in children and adults	Exp 1: 67 children aged 6–8, 22 adults; Exp 2: 263 children aged 6–13, 26 adults	Time reproduction task (E-Prime); mixed-effects models, Benjamini-Hochberg correction	Mixed design: age (between), speed/motion/duration (within)	1. Symbolic speed: fast (car/motorcycle), slow (truck/bike); 2. Motion: static vs dynamic; 3. Age: 6–13, adult; 4. Duration: 11s/21s (Exp 1), +36s (Exp 2)	Relative error: Ratio = reproduced / standard duration	Children aged 6–8 underestimated more for "fast" stimuli; All ages underestimated dynamic stimuli; Older children were more accurate; Longer durations were more underestimated

Serial Number	Author (Year)	Country	Research Purpose	Participants	Methods	Design	Key Independent Variables	Time-Related Dependent Variables	Key Findings
9	Qu et al. (2021)	China	To investigate the developmental trajectory of time perception accuracy in 3–5-year-olds and the effect of emotional face sequences	120 children: 3, 4, 5 years, 20 per group, balanced gender	Adapted time bisection task (E-Prime 2.0); training to 75% accuracy	Within-subjects: stimulus type, emotion sequence; Between-subjects: age group	1. Age group; 2. Stimulus type: non-emotional (black square) vs emotional (faces); 3. Emotion sequence: neutral-angry (N-A) vs angry-neutral (A-N)	1. Time judgment accuracy; 2. Reaction time	Accuracy increased with age; RT decreased; Larger duration differences improved accuracy; N-A sequence was more accurate than A-N
10	Martinelli & Droit-Volet (2023)	France	To examine the relationship between perceived duration and perceived speed of time passage in 4–9-year-olds, and the role of subjective experience	80 children: 34 aged 4–6 (young), 46 aged 7–9 (older)	Group testing; simulated scales for duration, speed, and subjective experience (emotion, arousal, difficulty)	Mixed design: within = time range (seconds/minutes) and interval; between = age group	1. Age group; 2. Time range: 13/27/53s vs 2/4/8min; 3. Subjective ratings: happiness, sadness, arousal, difficulty	1. Duration judgment; 2. Speed of time passage judgment	Young group judged time speed based on subjective experience (happiness, arousal), not duration; Older group linked speed to duration and emotion; Higher happiness/arousal → faster time; Young: harder task → faster time; Older: harder → slower
11	Hallez & Droit-Volet (2018)	France	To test whether children embody others' body states in time judgments and whether the theory of mind (ToM) modulates this	57 children aged 4–7 (M=6.05; 30 with ToM, 27 without)	Time reproduction task + Sally-Anne ToM test	Reference phase (learn 4s/8s) → test phase (reproduce after seeing silhouettes)	1. ToM: present/absent; 2. Others' body states: motion, object carrying, age, emotion	Normalized error: (reproduced - target)/target	All children showed embodiment: shorter reproduction for running/cycling, longer for crawling/carrying/old/sad. ToM children showed stronger distortions; 4s overestimated, 8s underestimated
12	Stojić et al. (2023)	Bosnia/ Hungary/ Croatia	To examine age-related differences in heuristic strategies used in duration estimation and their gestural expression	138 participants: 46 aged 4–5, 46 aged 9–10, 46 adults, gender balanced	Video presentation + verbal judgment + gesture coding; Chi-square/ANOVA	Retrospective duration comparison; videos balanced for order	1. Age group; 2. Event density: rich vs poor (both 60s)	1. Duration judgment; 2. Gesture metrics (direction, amplitude)	Young children judged event-rich videos as longer; Older children and adults judged event-poor videos as longer; Horizontal gesture use increased with age (adults 91%, 4–5y 57%); Amplitude did not differ

Serial Number	Author (Year)	Country	Research Purpose	Participants	Methods	Design	Key Independent Variables	Time-Related Dependent Variables	Key Findings
13	Segretin et al. (2024)	Argentina	To examine the effects of gender, temperament, and SES on interval timing in 4-year-olds	121 children aged 4–5 (58 girls, 63 boys); divided by SES: UBN (n=83) vs SBN (n=38)	1. Time reproduction task (2–4s); 2. Parent questionnaires: CBQ temperament, SES	Time reproduction accuracy and precision	1. Gender; 2. Temperament: effortful control, extraversion, negative affect; 3. SES: unmet vs satisfied basic needs	1. Accuracy at 2s, 3s, 4s; 2. Composite timing score	Girls outperformed boys at 2s, 3s, and total score; High effortful control > low at 2s (p=0.021); UBN group outperformed SBN at 4s and total score (p<0.05)
14	Sener & Starr (2025)	USA	To test whether linear mental timeline representation in 5–7-year-olds supports temporal order memory	96 children aged 5–7 (43 girls); English-speaking, mostly above-median income	1. Temporal memory: 3-choice event order/ placement after animation; 2. Mental timeline task: arrange icons for "yesterday/ today/tomorrow" and "morning/afternoon/ evening."	Preregistered cross-sectional	1. Mental timeline: linearity, direction; 2. Age (continuous 5.08–7.02y)	1. Temporal order accuracy; 2. Location memory accuracy	Children who produced linear arrays in both trials had higher temporal memory accuracy (β=0.21, p=0.02); Age correlated with both temporal (r=0.43) and location memory (r=0.29); Linearity was not associated with age
15	Autry et al. (2020)	USA	To test whether mental timeline development in early childhood is driven by literacy skills (cultural) or innate biases	65 children: preschool (35, M=3.87y) vs kindergarten (30, M=6.05y); English monolingual	1. Color card ordering task; 2. Print concepts task (0–13)	Cross-sectional	1. Early literacy: print concepts score, parent-reported independent reading; 2. Age group	1. Mental timeline direction (% left-right); 2. Ordering accuracy	Controlling for age, print concepts score predicted left-right temporal ordering (OR=1.80, p=0.005); Age no longer significant; Kindergarten: 95.3% left-right vs preschool: 55.3%; Both above chance
16	DeNigris & Brooks (2018)	USA	To investigate individual differences in middle childhood time cognition and their relation to language, nonverbal IQ, and working memory	62 children aged 6–10 (M=8y2m; 30 boys, 32 girls); language scores slightly above norm (CELF-4=105)	1. Time tasks: future distance estimation, time marking, month ordering; 2. Ability tests: PPVT-4, TROG-2, TONI-3	Cross-sectional	1. Language ability (PCA composite: vocab, grammar, reading); 2. Controls: age, nonverbal IQ, memory	1. Time marking accuracy; 2. Month ordering accuracy	Language ability uniquely predicted time marking (β=0.71, p<.001) and month ordering (β=0.52, p<.01), explaining 17.4% and 9.2% additional variance; Age effect disappeared when language added; Stronger prediction in 6–7-year-olds

Modulatory effects of emotions, situations, and individual differences

Temporal cognition does not exist in isolation; it is profoundly influenced by emotional states, task situations, the individual's environment, and their own traits. These factors indirectly change temporal judgment results by regulating the allocation of attention resources or the efficiency of the internal clock.

Dynamic influence of emotions and situations: emotional positioning and attention capture

The influence of positive and negative emotions on temporal perception is well known, but Qu et al.'s study introduced the nuanced variable of emotional positioning, revealing its dynamic nature.

In this study, 3-5-year-old children were shown two faces (angry and neutral), with the order of presentation varied to assess their perception of time duration. The researchers found that when the emotional stimulus appeared at the end (neutral-to-angry sequence), children's judgment of this time length was more accurate; when it was presented at the beginning (angry-to-neutral sequence), the judgment was inaccurate. The study found that the later emotional stimulus captured immediate attention, thereby promoting accurate timing during that period; the earlier emotional stimulus may dissipate early attention resources, thereby affecting the timing of subsequent neutral stimuli. This indicates that the influence of emotions on temporal perception is dynamic, depending not only on whether the emotion is positive or negative, but also on its position in the temporal sequence. This regulatory pattern tends to stabilize with age.

Interaction between socioeconomic status and temperament

Socioeconomic status and temperament affect temporal cognition through the "environment-individual trait" interaction, among which effortful control in temperament is a more direct and key factor. Segretin et al.'s study expanded the research dimension of temporal cognition by examining the interaction between socioeconomic status and individual temperament. The results showed that 4-year-old children from families with poor economic conditions were more accurate in judging longer durations. However, when researchers considered each child's temperament and gender, the direct effect of socioeconomic status (SES) on temporal cognition was no longer significant after controlling for these factors, and SES influence was observed only in the 4s duration task. This means that the initial finding that children from low-income families had a better sense of time was not directly caused by economic conditions. Finally, the study concluded that effortful control, a component of children's temperament, is a more direct and key factor. In addition, the study also found that female children were significantly better than male children in temporal reproduction accuracy ($p<0.05$), suggesting that gender may also regulate young children's temporal cognitive performance.

This result indicates that during early childhood, individual differences in temporal cognitive abilities are more strongly determined by children's innate or early-cultivated temperament than by broad environmental factors. Environment and traits jointly affect young children's temporal cognition, but individual characteristics have a more direct impact.

Development and transformation of representational styles

With the maturation of cognitive abilities, children's mental representation of time also undergoes a qualitative leap—from relying on specific external events and internal emotions to understanding and constructing pure, abstract temporal concepts; from being completely dominated by subjective feelings to integrating objective facts for logical judgment.

Martinelli and Droit-Volet's study brilliantly captured this transformation. They found that older children began to establish a connection between the speed of time passage and objective duration. In comparison, younger children were mainly driven by subjective emotional experience and had not integrated objective temporal information. The happier they played, the more they felt time "flew by", and they could not consider objective duration. However, by 8-9 years old, children had been able to integrate objective duration into their judgments and to understand that the longer the duration, the slower the perceived passage of time. This transformation is a key milestone in the development of children's temporal cognition: children transition from subjective judgment based on intuitive, concrete experience to the ability to think about and process abstract concepts. This is consistent with Piaget's cognitive development theory, which describes the transition from the preoperational to the concrete operational stage.

Stojić et al.'s study further revealed a fundamental transformation in children's intrinsic strategies for estimating time duration. They found a fundamental shift in children's time estimation strategies. 4-5-year-old children infer time based on the number and density of events—i.e., the more things happen and the richer the experience, the longer the time. Young children's time estimation is often closely linked to the number and density of events. 9-10-year-old children, on the other hand, learn to sample the pure flow of time and continuously estimate whether time is up. "I recalled several times and found that the process had not ended yet, so it must be long." This indicates that children at this stage have initially been able to separate time from events for independent thinking.

More notably, this transformation in duration estimation strategies occurs synchronously with changes in children's gesture use. Children aged 4-5 years have not yet formed a stable horizontal mental timeline; their time cognition relies on specific events, and their gesture directions are relatively chaotic. School-age children have developed the abstract concept of time as a left-to-right line and use horizontal gestures as their primary means of expression. It is worth noting that gesture amplitude did not differ significantly between age groups ($F=0.828$, $p=0.439$), indicating that directionality is more developmentally sensitive than amplitude. This suggests that knowledge and skills learned through formal education and cultural practices (such as left-to-right reading and writing) help school-age children and adults gradually represent time mentally as a horizontal timeline. This view is directly supported by Autry et al.'s study, which found that children's early literacy skills, rather than age itself, are a significant predictor of their tendency to form a left-to-right mental timeline. This indicates that the development of temporal cognition is not purely a matter of physiological maturation, but is shaped jointly by individual cognitive abilities and sociocultural environments.

Discussion

By setting comprehensive inclusion and exclusion criteria, this systematic review integrated 16 eligible studies to examine the core influencing factors affecting the development of young children's temporal cognitive abilities, as well as the mediating or moderating mechanisms through which these factors operate and their interaction modes. The results show that the development of children's temporal cognition is not a linear improvement in a single ability, but a qualitative transformation from concrete dependence to abstract thinking, driven by the interaction of core cognitive mechanisms, external situational factors, and individual traits. This development process is influenced by both physiological maturation and acquired environments and experiences, providing a more integrated perspective for understanding the nature of children's temporal cognition.

Developmental mechanisms of children's temporal cognition

The maturation and development of core cognitive mechanisms underlie children's temporal cognition, with the dynamic interaction between executive function and the internal clock system serving as the primary driving force for this development.

Inhibitory control and cognitive switching within executive function are essential for the accuracy of temporal perception and the orderliness of temporal memory. Inhibitory control and cognitive switching are not by-products of temporal processing, but prerequisites for its accurate performance. For accurate timing, children must inhibit responses to irrelevant stimuli, shift their attention to the timing task, and maintain sustained attention. Without these abilities, achieving accurate timing is challenging. Cognitive switching enables children to flexibly move between different events or tasks, which is the key to accurately judging the temporal order of events. The internal clock system, as the physiological basis, is influenced by increases in pacemaker frequency, and the enhancement of switch regulation efficiency directly affect the stability of temporal perception. At the same time, some higher cognitive abilities (such as attention and working memory) regulate the clock system, which further reflects the mutual promotion of physiological maturation and mental development.

It is worth noting that these two mechanisms do not work in isolation. The maturation of the internal clock system provides the physiological basis for temporal cognition, while executive function shapes children's active regulation of temporal processing. Together, they promote children's transformation from passive reception of temporal stimuli to active integration of temporal information.

Factors determining children's temporal cognition and their mechanisms of action

The development of children's temporal cognition is influenced and constrained not only by internal cognitive mechanisms but also by emotions, individual traits, and sociocultural environments.

The influence of emotions on temporal perception depends not only on their valence but also on their position in the temporal sequence. Subsequent emotional stimuli improve timing accuracy by affecting immediate attention, while prior emotions occupy attentional resources, thereby interfering with subsequent timing. This dynamic pattern tends to stabilize with age, reflecting the coordinated development of attention regulation and emotional processing. At the individual level, effortful control is a core trait of temporal cognition, and its predictive power is significantly higher than that of socioeconomic status (SES). Children with high effortful control can better maintain attention and therefore perform better in temporal tasks. In addition, the advantage of female children in temporal reproduction tasks further confirms the importance of gender as a moderating variable. Finally, cultural experience also profoundly shapes temporal cognition. Early literacy skills are a key predictor of children's formation of a left-to-right mental timeline, and their role extends beyond physiological maturation, indicating that cultural practices promote the transformation of temporal thinking from concrete to abstract by constructing abstract representational frameworks.

Developmental transformation of representational styles from concrete to abstract

The internal clock model has different meanings and interpretations in childhood and adulthood. Children interpret the number of pulses as the number of things that happened, while adults interpret it as the length of time itself. Therefore, a complete theory of temporal cognition must include an interpretation and representation module of the internal clock system. This module is not innate but is influenced by individual language ability, cultural experience, etc., thereby affecting how people convert the original signals of the internal clock into understandable temporal judgments; in addition, the core marker of the development of children's temporal cognition is the transformation of temporal representational styles from concrete imagery to abstract logic. The core marker of temporal cognition development is the shift from concrete to abstract representational styles—young children depend on specific cues. In contrast, older children construct logical connections between objective duration and time passage, supported by cultural experience and cognitive maturation. This transformation marks a shift in temporal cognition from sensory-driven to logical construction.

This representational transformation occurs simultaneously with the development of gesture expression. School-age children and adults use more horizontal gestures to represent time, forming a stable mental timeline. The establishment of this space-time association results from the interaction of cultural experience and cognitive development. The formation of the mental timeline provides children with an abstract tool for emporal thinking, enabling them to separate specific events and independently consider the length and order of time itself. This process closely aligns with the transition from the preoperational to the concrete operational stage in Piaget's cognitive development theory.

Conclusions

Based on 16 cross-sectional studies, children's temporal cognition develops from concrete to abstract, shaped by biological maturation and environmental factors. Conclusions are correlational (no causal inference) and generalizable only to typically developing children aged 3 to 10 years. Key findings: executive function and the internal clock system synergistically support development; emotions, effortful control, and early literacy are key factors; younger children rely on event density/emotions, while older children form abstract mental timelines. They may gradually construct more abstract temporal representations, for example, through the use of spatial or gestural timelines.

Implications

The findings of this study provide targeted references for preschool education and family education. The findings of this review contribute to a more nuanced theoretical understanding of children's temporal cognition by highlighting its developmental and multifaceted nature. The synthesis of the 16 studies suggests that temporal cognition is not a unitary ability but involves interactions among perceptual, cognitive, and affective processes that evolve with age and experience. In particular, the reviewed evidence suggests that executive functions and internal timing mechanisms may support developmental changes in how children represent and use temporal information. Moreover, the observed variability associated with emotional, individual, and sociocultural factors underscores the importance of conceptualizing temporal cognition as context-sensitive rather than uniform across children or situations. These insights refine existing developmental models by emphasizing the dynamic and integrative nature of temporal cognition across early and middle childhood.

Regarding the practical implications of the present literature synthesis, although the reviewed studies do not allow strong causal or prescriptive conclusions for educational practice, they suggest several directions for future research and practice. For example, the evidence indicates that younger children often rely on concrete, event-based cues when reasoning about time, whereas older children increasingly use more abstract representations. This developmental pattern suggests that age-appropriate supports—such as structured routines or visual representations of sequences for younger children and more abstract timeline-based activities for older children—could be explored and empirically tested in educational settings. In addition, some studies link aspects of temporal cognition to executive functions, suggesting that tasks involving temporal processing might serve as complementary indicators in developmental assessment, though further validation is needed.

At the family level, the findings suggest that everyday activities involving planning, waiting, and sequencing events provide natural contexts for supporting children's emerging understanding of time. However, these potential applications should be interpreted cautiously, as the current evidence base is largely descriptive and more intervention-focused, longitudinal research is required before firm educational recommendations can be made.

Research limitations and future directions

Overall, although existing research has achieved some results in children's temporal cognition, there are still significant limitations. Firstly, the sample is insufficiently representative. Research regions are mainly concentrated in European and American countries, with only 1 study from China. There is a lack of samples from non-Western cultural backgrounds, and the samples are focused on typically developing children from middle and high-socioeconomic status (SES) groups. Samples from low-SES groups, rural children, and special groups such as those with autism and attention-deficit hyperactivity disorder (ADHD) are scarce, making it challenging to reflect developmental differences across cultures and different environments.Secondly, there is considerable heterogeneity in research methods. All 16 studies adopt cross-sectional designs, which can only capture age differences and cannot track developmental trajectories. In addition, the parameters of the experimental tasks are not standardized, limiting the comparability of results. Thirdly, the breadth of research content is insufficient. The research focuses on current duration perception and temporal order memory of past events, with almost no exploration of future temporal cognition. Most studies examine the independent role of single factors, lacking analysis of the interaction mechanisms among multiple factors such as executive function, language ability, and SES. Finally, there is a disconnect between research results and practice. Some studies have not transformed key findings into actionable educational intervention programs, and a complete closed loop from basic research to practical application has not been formed.

Based on this, future research needs to expand sample diversity, increase samples from non-Western cultures, special groups, and low-SES groups to improve generalizability; promote the standardization and longitudinalization of research methods to clarify causal relationships; deepen the exploration of core mechanisms, examine the interaction of multiple factors, and explore the neural basis using technologies such as EEG and fNIRS; strengthen practical transformation, design intervention programs for temporal cognition, early literacy, and executive function training, and integrate them into daily activities; at the same time, expand research on future temporal cognition and the impact of digital media use on children's temporal cognition to improve the research framework of children's temporal cognition.

Authors' contributions

All authors contributed to the study conception and design. The author conducted the literature search, screening, data extraction, and quality assessment, and drafted the initial manuscript. Critical revisions on the intellectual content were provided by all co-authors (if applicable; otherwise, delete this clause). All authors read and approved the final manuscript for submission.

Conflicts of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Institutional review board statement

This study is a systematic review that does not involve primary research on human subjects or animals. Therefore, ethical approval is not applicable and informed consent is not required.

Informed consent statement

This systematic review synthesizes existing empirical studies and does not involve direct participation of human subjects. Thus, informed consent is not required.

Permissions information

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