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## Cognitive Development

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# The development of susceptibility to geometric visual illusions in children – A systematic review

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## ARTICLE INFO

## Keywords:

Visual illusions  
Susceptibility  
Development  
Systematic review  
Visual perception

## ABSTRACT

Investigating children's susceptibility to visual illusions (VIs) offers a unique window into the development of human perception. Although research in this field dates back to the seminal work of Binet in 1895, developmental trajectories for many VIs remain unclear. Here, for the very first time, we provide a comprehensive systematic review of research investigating children's susceptibility to five of the most famous VIs: the Ebbinghaus, Ponzo, Müller-Lyer, Pogendorff, and Vertical-Horizontal illusions. Following PRISMA best-practice guidelines, 70 articles were identified across four databases (Scopus, PsycInfo, PsycArticles, and Web of Science). Our findings reveal opposing developmental trends across illusions; the magnitude of the Müller-Lyer, Pogendorff, and Vertical-Horizontal illusions tends to decrease with age, while the magnitude of the Ebbinghaus and Ponzo illusions typically increases with age. However, developmental trajectories identified by studies investigating the same illusion can vary dramatically due to substantial variability in methods and stimuli. Researchers are more likely to find decreasing VI magnitude with increasing age when employing the method of adjustment response paradigm, whereas the two-way alternative forced-choice paradigm typically reveals greater VI magnitude with increasing age. These findings suggest that conclusions regarding the development of VI susceptibility may be influenced by how they are studied and implicate the involvement of different cognitive abilities across response methods. These findings will benefit future research in dissociating the role of perceptual (e.g. the maturation of the brain's visual areas) and cognitive factors (e.g., attention span) in pinpointing the development trajectories for VI susceptibility.

A visual illusion (VI) occurs when our perception of an object's physical properties departs from physical reality (Gregory, 1998; Notredame et al., 2014). VIs have been employed by researchers to explore a range of visual mechanisms, including the ventral and dorsal perceptual streams (e.g., Knol et al., 2017), neuroanatomical differences (Schwarzkopf et al., 2011), and abnormalities in visual perception in neuropsychological conditions such as schizophrenia (Costa et al., 2023; King et al., 2017) and autism (Gori et al., 2016). VIs also offer a unique window into the development of human perception, as different VIs are thought to be subserved by different perceptual, cognitive, and neural mechanisms (King et al., 2017). Thus, studies investigating developmental trajectories for VI susceptibility can provide valuable insight into the emergence and maturation of these mechanisms. Here, we provide the very first systematic review of research investigating how susceptibility to a range of VIs evolves over the course of children's development.

Research investigating children's VI susceptibility has advanced our understanding of cognitive development in several important

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<https://doi.org/10.1016/j.cogdev.2023.101410>

Received 20 June 2023; Received in revised form 22 October 2023; Accepted 20 November 2023

Available online 9 December 2023

0885-2014/© 2023 The Author(s).

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ways. Firstly, VIs provide insight into how human visual perception – including depth perception, size constancy, and spatial perception – develops over time (e.g., Leibowitz & Judish, 1967; Pressey, 1974). Documenting the development of these perceptual mechanisms is essential for understanding how children process the visual world. Research has discovered that children’s susceptibility to most VIs changes over time. Curiously, the magnitudes of some VIs appear to *decrease* with age (e.g., the Müller-Lyer; Grzechowski et al., 2017), while the magnitudes of others *increase* with age (e.g. the Ebbinghaus illusion; Doherty et al., 2010). However, research has yet to explain these contrasting developmental trajectories, and different studies investigating the same illusion can yield conflicting results. For example, it has been reported that the Ponzo illusion both increases (Freud et al., 2021) and decreases (Pressey & Wilson, 1978) in magnitude as children get older. Similar incongruent susceptibility trends have been observed for other VIs, including the Ebbinghaus, Poggendorff, and Vertical-Horizontal illusions (Chouinard et al., 2013; Doherty et al., 2010; Hanley & Zerbolio, 1965). A systematic review of the field is necessary to identify and understand the possible causes of these empirical inconsistencies, which represent a major obstacle to understanding how visual perception develops during childhood.

The objective of this comprehensive systematic review is to identify, synthesise, and evaluate research investigating the development of children’s susceptibility to five prominent VIs: the Ebbinghaus, Ponzo, Müller-Lyer, Poggendorff, and Vertical-Horizontal illusions. The findings of this review will consolidate the current state of knowledge regarding developmental susceptibility trends and yield insight into why studies measuring the same illusion observe different developmental trajectories. We will explore whether heterogeneity in extant literature can be attributed to methodological and stimuli inconsistencies and the possibility that differences in children’s VI susceptibility could be due to immature responding strategies (rather than differences in perception). Crucially, the results of this review will advance the field and theory-making by disentangling how researchers’ methodological decisions impact on children’s perception of VIs and their strategy use.

## 1. Method

The PRISMA statement (Page et al., 2021) was used to conduct and report our systematic review. No protocol was registered for this

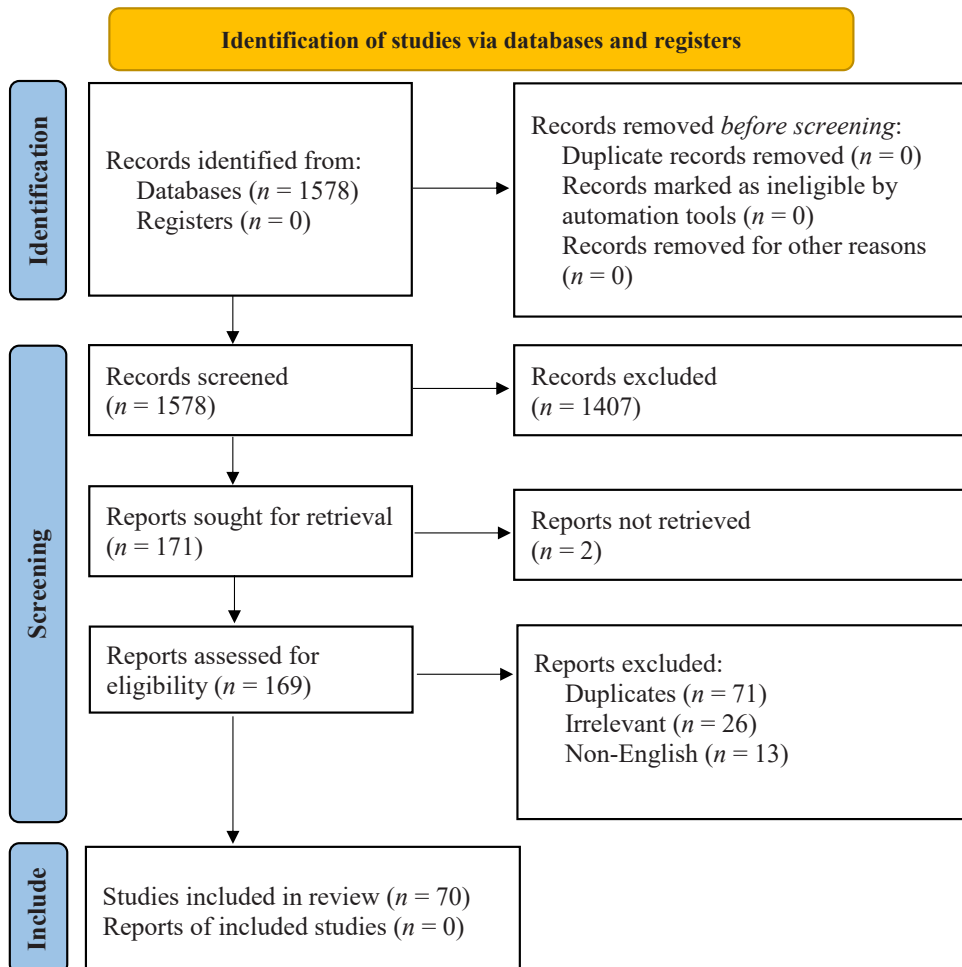


Fig. 1. PRISMA Flow Chart. Note. Summary of literature search and selection process.

review.

### 1.1. Eligibility criteria

For a study to be included in this systematic review, the following criteria had to be satisfied: 1. Participants must be children (between 3 and 16 years of age) without neurodevelopmental conditions (e.g., autism), mental health conditions (e.g., depression), or vision impairments (e.g., strabismus), 2. The study had to compare samples of differently-aged children, or children and adults, 3. The study had to describe their methodology in sufficient detail (i.e., what method was used to measure children's susceptibility to VIs), 4. The study had to include primary data, 5. Ponzo-like effects, elicited by stimuli other than two horizontal lines (e.g., circles, see Grzeczowski et al., 2017), were excluded from the review. The rationale for this exclusion was to maintain internal consistency among the reviewed studies, i.e., their versions of the illusion were highly similar (see the 'Variations in Stimuli' section for further discussion), 6. The study had to be written in English.

### 1.2. Search

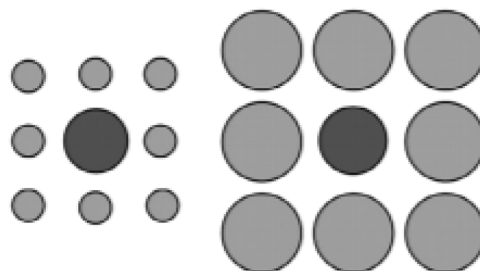
The systematic search was conducted in November 2022. Two strings of keywords were used; "visual illusion\* " OR "optical illusion\* " OR "ebbinghaus illusion" OR "titchener circles" OR "müller-Lyer illusion" OR "muller lyer illusion" OR "pogendorff illusion" OR "ponzo illusion" OR "vertical-horizontal illusion" OR "horizontal-vertical illusion" OR "vertical horizontal illusion" OR "horizontal vertical illusion", and child\* OR infant\* OR juvenile\* OR adolescent\* OR kid\* OR teen\* . The search was conducted on titles and abstracts alone on Scopus, PsycInfo, PsycArticles, and Web of Science databases yielding 736, 609, 58, and 175 articles, of which 52, 77, 8, and 32 met the inclusion criteria, respectively (see Fig. 1).

### 1.3. Study selection

Both the first and third authors searched the databases independently and extracted relevant studies following the inclusion criteria described above. After selecting studies based on their relevance, the reviewers jointly compared extracted studies ( $n = 169$ ) from all four databases. A high internal agreement between the reviewers was obtained; 94% of studies ( $n = 159$ ) were selected by both reviewers as being relevant. Discrepancies were re-evaluated by the reviewers and decisions were reached through discussion. Further inspections of full texts led to exclusions due to failure to meet the inclusion criteria ( $n = 15$ ), duplication ( $n = 62$ ), and being written in a language other than English ( $n = 13$ ). Therefore, the final sample consisted of 70 papers reporting 83 trends (either no differences, increasing, or decreasing susceptibility with age).

## 2. Common methodologies

Before discussing the findings of previous studies exploring children's susceptibility to VIs, it is crucial to understand the various response methods they employ such as the two-alternative forced-choice paradigm (2AFC), the method of adjustment, the method of production, the same-different method, and the up-and-down method. Though some of these methods are comparable in nature, differences between them could potentially account for discrepancies in findings between studies investigating the same illusion. Specifically, different response methods may draw upon distinct cognitive mechanisms that develop at different rates. For example, the 2AFC simply requires participants to compare and identify which of two illusory targets is smaller/larger/longer/shorter/darker/brighter (Doherty et al., 2010). By contrast, moving beyond visual discrimination, the method of adjustment requires participants to adjust an illusory target so that it matches another (which is usually very different) on particular physical properties (Hadad, 2018). The method of production is very similar to the method of adjustment, with the minor difference being that the target part of an illusion has to be created by the participant, usually by hand. The same-different method asks participants to indicate whether the target components of illusions are physically identical or different (i.e., binary same/different decision; Barclay & Comalli, 1970). Finally, the up-and-down method tests each participant only once, and stimuli are determined by the previous participant's response (Hanley & Zerbolio, 1965; Weintraub, 1979). For example, if Participant 1 adjusted the target line to be 10 cm, which is their perceived equality,



**Fig. 2.** The Ebbinghaus Illusion. Note. A version of the Ebbinghaus illusion as used by Bremner et al. (2016). The middle circle on the left appears larger, however, the middle circle on the right is 6% larger.

then Participant 2 would view the comparison target to be 10 cm. Then, if that participant found it to be inadequate and adjusted it down or up by one centimetre, the next participant would view the comparison line at 9 cm or 11 cm.

### 3. Age trends in susceptibility to visual illusions

#### 3.1. The Ebbinghaus illusion

Created by Hermann Ebbinghaus, and popularised by Edward Titchener (the illusion is sometimes referred to as the ‘Titchener circles’; Roberts et al., 2005), the Ebbinghaus illusion is one of the most studied illusions in developmental research. In its classic form, two identically sized circles are surrounded by larger or smaller circles (see Fig. 2). This presentation causes the viewer to overestimate the size of the circle surrounded by smaller circles, perceiving it as larger.

#### 3.2. Summary of findings

Many studies using the 2AFC have reported that the magnitude of the Ebbinghaus illusion increases gradually from around 4 or 6 years of age (Doherty et al., 2010; Kaldy, & Kovacs, 2003; Küttik et al., 2023; Schulze et al., 2022; Thelen & Watt, 2004; Zanuttini, 1996; see Table 1 for an overview of all studies on the Ebbinghaus illusion). Similarly, using the up-and-down method, Weintraub (1979) showed that children’s susceptibility to the illusion increases with age. Using the method of adjustment, Mavridis and colleagues (2020) also report an increasing magnitude of the illusion with age in children aged 5–15 years. Cross-culturally, the 2AFC has yielded similar age-related trends in Japanese and Chinese children aged 4–9 years, although these groups both show a greater illusion effect compared with similarly-aged US or German children (Imada et al., 2013; Schulze et al., 2022). The emergence of the Ebbinghaus illusion may be delayed in Namibian children (until around 9 years) in comparison to UK children, but the direction of

**Table 1**  
Studies Investigating the Developmental Trends of Susceptibility to the Ebbinghaus Illusion.

Study	Sample	Design	Main finding
Doherty et al. (2010)	151 children aged 4–10, 24 adults	2AFC	Illusion’s magnitude increases with age.
Hanisch et al. (2001)	34 children aged 5–12, 11 adults	Method of adjustment	No differences in susceptibility between children and adults.
Zanuttini (1996)	120 children aged 4–10	2AFC	Illusion’s magnitude increases with age.
Duemmler et al. (2008)	42 children aged 5–9	Method of adjustment	No difference.
Kaldy & Kovacs (2003)	13 children aged 4, 15 adults	2AFC	Illusion’s magnitude increases with age.
Bondarko & Semenov (2004)	274 children and adolescents aged 6–16 and 23 adults	2AFC	Illusion’s magnitude decreases with age.
Weintraub (1979)	386 children aged 6–12 years, 36 adults	Up-and-down	Illusion’s magnitude increases with age.
Hadad (2018)	40 children aged 4–8, 20 adults	Method of adjustment	Illusion’s magnitude increases with age when the contextual circles were bigger, but no difference was observed when they were smaller.
Hadad (2018)	12 children aged 4–5, 12 adults	2AFC	No significant difference between adults and children (though a reduced illusion size with age was indicated by the results).
Thelen & Watt (2010)	Children aged 4–9 and adults.	2AFC	Illusion’s magnitude increases with age.
Bremner et al. (2016)	116 Namibian children aged 3–17 and 34 Namibian adults, and 37 children aged 3–10 were selected from the Doherty et al. (2010) study, and 45 children aged 11–17 and 28 adults	2AFC	Illusion’s magnitude increases with age for both children in Namibia and the UK though an increase in susceptibility had a later onset in Namibian children.
Imada et al. (2013)	175 children aged 3–10 (89 from the USA and 86 from Japan)	2AFC	Illusion’s magnitude increases with age. Japanese children show greater illusion.
Coren & Porac (1978)	668 children and adults aged 5–70	Selecting a matching circle from a set of comparison circles	An increase with age for smaller surroundings, and a decrease with age for larger surroundings.
Schulze et al. (2022)	261 children aged 4–6	2AFC	Illusion’s magnitude increases with age.
Mavridis et al. (2020)	297 children aged 5–15	Method of adjustment	Illusion’s magnitude increases with age.
Küttik et al. (2023)	245 children aged 6–10 years of age and 57 adults	2AFC	Illusion’s magnitude increases with age.
Grzeczowski et al. (2017)	144 participants aged 6–81	Method of adjustment	Illusion’s magnitude decreases with age.

*Note.* A total of 16 studies (Hadad, 2019 reports two separate experiments) on the developmental trajectory of the Ebbinghaus illusion have been included in the review.

their developmental trajectory does not differ (Bremner et al., 2016).

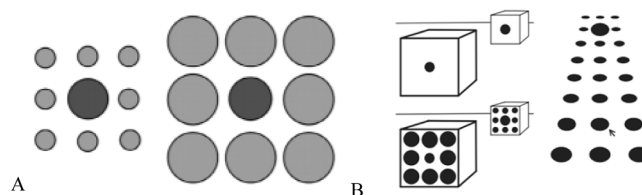
However, the developmental trajectory for the Ebbinghaus illusion susceptibility is not universally consistent (Doherty et al., 2010). Using the method of adjustment, Hanisch et al. (2001) and Duemmler et al. (2008) found no differences between children aged 5–12 years and adults, while Grzeczowski et al. (2017) showed that susceptibility to the illusion declines with age in participants aged 6–81 years of age. Using the 2AFC, Bondarko and Semenov (2004) showed that susceptibility to the Ebbinghaus illusion decreases with age in children aged 6–17 years of age. Finally, Hadad (2018) reports a decreasing trend in children aged 4–8 years of age using both the 2AFC (though the results failed to reach significance) and method of adjustment (children were more susceptible when the contextual circles were bigger, but no difference was observed when they were smaller).

The decreasing magnitude of the illusion observed by Hadad (2018) and Bondarko and Semenov (2004) may be attributable to their stimuli. Unlike other research using 2AFC to measure the Ebbinghaus illusion (e.g., Doherty et al., 2010), in these two studies, the comparison circle was presented in isolation without any surrounding circles, while the other circle was presented with either smaller or larger surrounding circles (these compositions of the Ebbinghaus illusion allow for distinguishing the role of surroundings on susceptibility). Hadad (2018) reports that for both 2AFC and the method of adjustment, susceptibility declines with age for the larger surroundings. This finding aligns with Coren and Porac (1978), who showed that susceptibility to the Ebbinghaus illusion increases with age if, in the selected set of stimuli, a sole circle is compared against a circle with smaller surroundings. Conversely, comparing a sole circle against a circle with larger surroundings results in decreasing magnitude with age. Similarly, Kaldy and Kovacs (2003) and Zanuttini (1996) report that children aged 4–10 years are less susceptible to the Ebbinghaus illusion when an isolated circle is presented next to a circle with larger surroundings. Though not significant, the opposite trend was observed for smaller surroundings, contrary to the findings by Coren and Porac (1978). This discrepancy might be due to employing a different method; Coren and Porac asked children to match a circle from a set of comparison circles to the target (an uncommon method in the field), while the above studies used the 2AFC. Thus, a number of studies indicate that susceptibility to the Ebbinghaus illusion decreases with age when an isolated circle is presented next to a circle with smaller surroundings, but increases when presented next to a circle with larger surroundings. However, it is important to note that these studies do not measure a complete Ebbinghaus illusion, only its reduced form (which is considerably weaker in magnitude; Kaldy & Kovacs, 2003). While such experiments usefully measure the mechanisms of the illusion and the interplay between its parts, the claims made based on those experiments must be carefully extended to the Ebbinghaus illusion as a whole.

### 3.3. Theoretical explanations

Two of the most prominent psychological theories explaining the Ebbinghaus illusion are proposed by Doherty et al. (2010) and Kaldy and Kovacs (2003). The former proposes that the human visual system's inability to correctly interpret certain depth cues results in perceiving 2D images as 3D scenes, distorting the physical properties of the stimulus. However, in the case of the Ebbinghaus illusion, these cues are not salient enough to cause an explicit perception of depth. Consequently, the circle with smaller surroundings is perceived as further away and is therefore perceived to be bigger (see Fig. 3 for a comparison of the classic Ebbinghaus illusions and the Ebbinghaus with more explicit depth cues). By contrast, context sensitivity theory explains the Ebbinghaus illusion in terms of how context is automatically integrated by the human visual system (Kaldy & Kovacs, 2003). This account proposes that top-down influences bind the illusion's elements in perception, resulting in the distortion of physical properties. These top-down influences are based on expectations, previous knowledge, and the global picture, which results in "seeing the forest before the trees" (i.e., focusing on the whole picture, rather than its parts; Burghoorn et al., 2020). Thus, although the two target circles are judged independently of each other, perception of size is influenced by their surroundings which leads to the illusory effect.

Depth cue and context sensitivity theories have both been employed to explain why the Ebbinghaus illusion's magnitude appears to increase with age. Kaldy and Kovacs (2003) propose that younger children's reduced ability to integrate context decreases their susceptibility to the Ebbinghaus illusion – by not binding the illusion's elements (the target circles and their surroundings) together, children are more accurate in their judgments because they focus on local elements rather than the global picture. This theory is supported by evidence that children younger than 9 years are less reliant on top-down influences during free visual inspections of scenes and focus more on the local parts of stimuli rather than holistic meaning (Açık et al., 2010). Also, in visual search tasks, young children are less able to rely on top-down mechanisms than adults (Donnelly et al., 2007). If children are prone to focus exclusively on the most salient features of the illusion (usually the inner circles are a different colour than the surroundings; e.g., Doherty et al., 2010), this would yield a percept of size that is largely independent of the surroundings. Indeed, Kaldy and Kovacs (2003) showed that 4-year-old children are as accurate as adults in size discrimination when only the middle circles are present with no distractors or



**Fig. 3.** Comparison of the Classical Version of the Ebbinghaus Illusion and an Alternative Version with Explicit Depth Cues. Note. The A version of the Ebbinghaus illusion has no explicit depth cues, compared to the B version on the right. Both versions come from Doherty et al. (2010).

pictorial depth, indicating that the ability to discriminate size develops relatively early. The maturation of mechanisms underpinning global perception (which relies on knowledge and expectations) may consequently result in gradually increasing VI susceptibility. Thus, weaker top-down and stronger bottom-up influences could account for children's reduced susceptibility to the Ebbinghaus illusion.

Alternatively, Doherty and colleagues (2010) hypothesise that children's reduced ability to perceive pictorial depth causes them to be less susceptible than adults to the Ebbinghaus illusion. Because the illusion may be contingent on perceiving the target circle surrounded by smaller circles as being further away compared to the target circle with larger surroundings, children's reduced ability to perceive depth may affect their sensitivity. This hypothesis aligns with Bower's (1977) observation that adults perceive a miniature object as being a normal size but further away than it actually is, while children up to six years of age provide more accurate estimates of size and distance. On the other hand, adults are likely to perceive an oversized object as normally-sized but closer in distance, while young children do not. Jahoda and McGurk (1974) showed that children's ability to accurately estimate size in pictures with pictorial depth improves from 4–10 years. Conversely, children's spatial accuracy is poor below the age of 8 years, but rapidly increases to reach an adult-like level around 10 years. Therefore, children's reduced ability to integrate depth cues correctly might result in decreased susceptibility to the Ebbinghaus illusion.

To summarise, although the majority of studies suggest that susceptibility to the Ebbinghaus illusion increases with age, differences in stimuli and methodology prevent the developmental trajectory from being accurately and reliably profiled.

#### 4. The Ponzo illusion

The Ponzo illusion was actually first discovered by Edmund C. Sanford (Bertamini & Wade, 2023), but is incorrectly credited to Mario Ponzo (e.g., Donaldson & Macpherson, 2017). The illusion consists of two parallel and identically long lines, one of which is perceived to be longer than the other due to converging lines in the background getting closer together (see Fig. 4).

##### 4.1. Summary of findings

An early study by Leibowitz and Judisch (1967) using the 2AFC found that the magnitude of the Ponzo illusion increases with age (an overview of all studies on the Ponzo illusion can be found in Table 2). Numerous other studies have corroborated this finding using the same method (Brislin, 1974; Farquhar & Leibowitz, 1971; Freud et al., 2021; Quina & Pollack, 1972; and Wagner, 1977). These studies all employed a vertical version of the illusion, except for Brislin (1974) who used both vertical and horizontal versions, and only differ in their reporting of *when* children start to exhibit an adult-like level of processing – varying from 7 years (Leibowitz & Judisch, 1967) to 15 years of age (Farquhar & Leibowitz, 1971). Pressey (1974) proposes that researchers have identified different ages at which susceptibility to the Ponzo illusion reaches an adult-like level due to variation in stimuli. For example, using stimuli in which the two lines are interrupted by several converging lines elicits an illusion of greater magnitude (as in Farquhar & Leibowitz, 1971; Leibowitz & Judisch, 1967), which is more likely to be perceived at younger ages.

However, as for the Ebbinghaus illusion, studies disagree on the direction of the Ponzo illusion's developmental trajectory. Utilising the method of adjustment, Cretienoud et al. (2020) and Pressey and Wilson (1978) report decreasing illusion magnitude with age for horizontal versions of the illusion. By contrast, using the method of adjustment and a horizontal version of the illusion, Hadad (2018) reports increasing magnitude with age in children aged 4–8 years of age, whereas Granrud and Granrud (2004) found no differences between children aged 4–5 years and adults. It is worth noting that Cretienoud and colleagues (2020) used a version of the Ponzo illusion where one of the lines was placed outside of the illusory context, which could potentially reduce the strength of the illusion. In adults, such presentations of this illusion affect the perceived size of the top line more than the bottom line due to an increased number of fixations in the upper visual field (Yildiz et al., 2019b).

Crucially, developmental trends for the Ponzo illusion may differ depending on its orientation and complexity. Using the up-and-down method, Hanley and Zerbolio (1965) found that children's susceptibility to the Ponzo illusion increases with age when the illusion is vertical, but decreases with age when the illusion is presented horizontally. It is proposed that this discrepancy could be due to the human brain processing these two versions of the illusion differently, meaning that they have separate developmental trajectories. As depth percept for the vertical version is stronger, increasing susceptibility with age could be explained by developmental

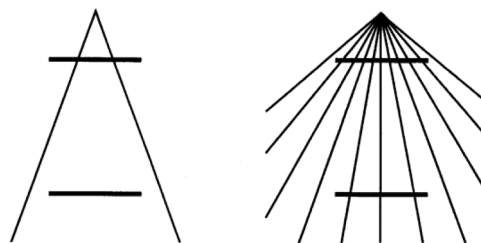


Fig. 4. The Ponzo Illusion. Note. Two versions of the Ponzo illusion presented by Miller (2001). The line on the top is perceived as longer than the bottom line, however, both lines are equal in length. The example on the left is considered to be the simple version, while the example on the right is considered to be a complex version of the illusion.

**Table 2**  
Studies Investigating the Developmental Trends of Susceptibility to the Ponzo Illusion.

Study	Sample	Design	Main finding
Hanley & Zerbolio (1965)	1422 children aged 3–12, and 202 adults	Up-and-down	Illusion's magnitude increases in susceptibility when the illusion is vertical but produces a decrease when the illusion is presented horizontally.
Wagner (1977)	386 participants aged 7–22	2AFC	Mixed results depending on factors like whether the person was schooled or lived in an urban or rural setting. Classical Ponzo for urban schooled children – an increase with age.
Leibowitz & Judish (1967)	427 participants aged 3.5–88	2AFC	Illusion's magnitude increases with age.
Freud et al. (2021)	17 children aged 5–8, 18 adults	2AFC	Illusion's magnitude increases with age.
Cretenoud et al. (2020)	76 participants aged 6–66	Method of adjustment	Weak decrease in susceptibility with age (though no significant interactions between different contexts and age).
Quina & Pollack (1972)	70 children aged 7–14 and 10 adults	2AFC	Increase and then decrease in susceptibility with age.
Pressey & Wilson (1978)	116 children aged 5–9	Method of production	Illusion's magnitude decreases with age.
Hadad (2018)	40 children aged 4–8, 20 adults	Method of adjustment	Illusion's magnitude increases with age.
Farquhar & Leibowitz (1971)	168 children aged 3–13, 260 older children, and adults	2AFC	Illusion's magnitude increases with age.
Granrud & Granrud (2004)	20 children aged 4–5, 40 adults aged 20–90	Method of adjustment	No differences between children and adults.
Brislin (1974)	320 participants aged 3–22	2AFC	Illusion's magnitude increases with age.
Pressey (1974)	222 children aged 5–17	Method of production	Illusion's magnitude decreases with age.

*Note.* A total of 12 studies on the developmental trajectory of the Ponzo illusion have been included in the review.

improvements in children's depth perception (e.g., [Jahoda & McGurk, 1974](#)). Conversely, as depth percept is weaker for the horizontal version, younger children's less accurate perception may be attributable to their reduced ability to integrate context ([Kaldy & Kovacs, 2003](#)). This may explain why [Cretenoud and colleagues \(2020\)](#) and [Pressey and Wilson \(1978\)](#) found decreasing magnitude with age, as both used the horizontal version of the illusion.

[Wagner \(1977\)](#) reports that in children as young as five years and adults aged 18–22 years, susceptibility to a complex version of the Ponzo illusion increased with age, while susceptibility to a simple version decreased with age. Using a very simplistic horizontal version of the illusion (with only two converging lines), [Pressey and Wilson \(1978\)](#) also reported decreasing susceptibility to the Ponzo illusion with age in children aged 5–9 years. However, these data do not align with more recent results (e.g., [Hadad, 2018](#)). Though the method of adjustment (used by [Hadad, 2018](#)) and method of production (used by [Pressey & Wilson, 1978](#)) are almost identical in what they are trying to achieve, they could still elicit differences in observed results. The method of production relies on the participant drawing a line by hand. As the ability to draw relies upon imagery, motor output, and control processes that develop with age ([Del Giudice et al., 2000](#); [Toomela, 2002](#)), younger children's less accurate lines may reflect their immature drawing capabilities rather than their susceptibility to the illusion.

[Brislin \(1974\)](#) found increasing susceptibility with age for both vertical and horizontal orientations of the Ponzo illusion. However, these illusions included a greater number of converging lines (lines that bisect the target lines) than most other studies, thereby enhancing depth cues and the illusion's magnitude. [Cretenoud and colleagues \(2020\)](#) tested participants aged 6–66 years of age on three versions of the Ponzo illusion (all horizontal): perceptually poor (geometric, with only two converging lines), perceptually moderate (geometric, with multiple converging lines), and perceptually rich (rail track). Perceptually poor and rich contexts both yielded decreasing susceptibility with age. These findings suggest that the horizontal version of the illusion decreases in magnitude with age ([Hanley & Zerbolio, 1965](#)), but opposes [Wagner's \(1977\)](#) findings that older children are increasingly susceptible to more complex illusions.

Other potential explanations for heterogeneity in findings across Ponzo illusion studies concern environmental and gender differences. Cultural differences have been found to play a major role in susceptibility to the Ponzo illusion ([Brislin & Keating, 1976](#); [Leibowitz & Pick, 1972](#)). For example, the illusion is weaker in magnitude in Ugandan and Guam university students compared to American students, and the illusion is virtually absent in Ugandan villagers ([Leibowitz & Pick, 1972](#)). Reduced illusion susceptibility in these cultures has been attributed to differences in their visual experiences (e.g., time spent viewing photographs or pictures), which shape the development of visual perceptual mechanisms ([Leibowitz & Pick, 1972](#)). Differences in visual experience may also explain children's reduced susceptibility to the Ponzo illusion; reduced experience viewing 2-dimensional stimuli may cause a weaker percept of depth, resulting in more accurate line length judgements. The Ponzo illusion is also found to be of increased magnitude in females, relative to males ([Miller, 1999, 2001](#)). Thus, it is possible that [Wagner's \(1977\)](#) results were influenced by their sampling of only Moroccan males.

## 4.2. Theoretical explanations

As for the Ebbinghaus illusion, both context sensitivity and the ability to perceive pictorial depth could be proposed as explanations for the Ponzo illusion. Context integration is crucial to the Ponzo illusion; the converging lines may cause illusory effects due to being bound together in perception. Conversely, local and stimulus-driven elements are perceived due to bottom-up influences – focusing on the local elements of stimuli rather than the global picture (Burghoorn et al., 2020). In other words, illusory depth is not perceived if the local elements of the Ponzo illusion are not integrated together, resulting in the two lines appearing to be identical lengths.

The Ponzo illusion is also a traditional example of a depth illusion. Gregory (1963) suggested that the Ponzo illusion is experienced because the perception of depth occurs automatically, and the converging lines are interpreted as depth cues. As the converging lines get closer together at the top of the picture (mimicking a vanishing point), the top line is perceived as being ‘further away’. Because we ‘misapply’ size constancy to combat the retinal image’s tendency to enlarge with distance, the upper line is perceived as longer because it is assumed to be further away (Sperandio & Chouinard, 2015). Recently, Yildiz et al. (2022a) proposed that the Ponzo’s depth illusion could be the result of accumulated visual experience. Their theory is underpinned by the Bayesian concept of ‘prior probability’ - a probability distribution that considers previous knowledge/information about a particular parameter before a process occurs (i.e., previously observed pictures will impact the perception of a new picture). Hence, based on prior experience of viewing depth in pictures, objects in the upper visual field are assumed to be further away, whereas objects in the lower visual field are assumed to be ‘closer’.

Decreased magnitude of the Ponzo illusion in young children could be explained by their reduced ability to integrate context due to weaker top-down influences that bind local elements together in perception. Yildiz et al. (2019b) propose that top-down influences impact susceptibility to the Ponzo illusion more than bottom-up influences because gaze is directed more often toward the upper visual field. It is possible that young children explore the top line to a greater extent than adults because it is more perceptually engaging, resulting in reduced susceptibility. This speculation is supported by evidence that the upper visual field favours local (bottom-up) over global (top-down) processing (Thomas & Elias, 2011), and stronger reliance on local elements should reduce the illusion’s strength. Alternatively, or additionally, decreased susceptibility may be attributable to young children’s reduced ability to perceive pictorial depth (up to the age of approximately seven years; Doherty et al., 2010). In line with these hypotheses, the majority of studies show that susceptibility to the most simple form (geometrical) of the Ponzo illusion increases with age up to around 15 years of age, implying that children’s ability to interpret depth cues and/or combine local elements develops through the majority of childhood.

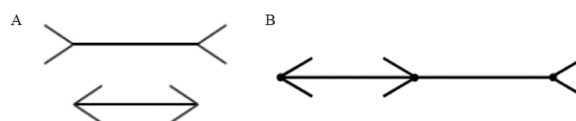
## 5. The Müller-Lyer illusion

Created by Franz Carl Müller-Lyer in 1889 (Donaldson & Macpherson, 2017), the Müller-Lyer illusion (see Fig. 5) is a popular illusion in developmental research. In its classic form, two equally long horizontal lines are presented in parallel to each other. One of the lines has arrowheads pointing outwards, and one has arrowheads pointing inwards. The arrowheads pointing outwards make the line appear longer. In another version, the illusion is presented as one straight line, with two arrowheads pointing either inwards or outwards, and one arrowhead in the middle pointing in either direction. This version is sometimes referred to as ‘Brentano’s Müller-Lyer illusion’ (Predebon, 1998) or the ‘Brentano illusion’ (de Grave et al., 2006).

### 5.1. Summary of findings

Age-related findings from studies investigating the Müller-Lyer illusion show an opposite pattern to the Ebbinghaus and Ponzo illusions and tend to be more consistent (an overview of all studies on the Müller-Lyer illusion can be found in Table 3). A number of studies have shown that susceptibility to the Müller-Lyer *decreases*, rather than increases with age, regardless of the method used. In a pioneering study using the same-different method, Binet (1985) (as translated by Pollack and Zetland, 1965) showed that children aged 9–12 years are more susceptible to the Müller-Lyer illusion than adults. Using the method of adjustment, Rivers (1905) and Walters (1942) attained similar results in children and adolescents aged 6–19, while Pinter and Anderson (1916) showed that susceptibility to this illusion decreases with age in children between 6 and 17 years. These results have since been replicated, using identical methods, by Girgus and colleagues (1975), Houghton and Tabachnick (1979), Johnson and Jackson (1974), Grzeczowski et al. (2017), and Cretenoud et al. (2020). Also, using the method of adjustment, Ahluwalia (1978) reported that Zambian children show a similar developmental trajectory as children from Western countries – younger children are more susceptible to the illusion than older children.

Dawson et al. (1973), Ebert (1976), Pathak and Joshi (1986) and Pollack (1963, 1970) used the 2AFC and obtained analogous results: younger children aged 6–12 years were more susceptible to the Müller-Lyer illusion than older children aged 12–18 years or



**Fig. 5.** The Müller-Lyer Illusion. Note. A: The classic version of the Müller-Lyer illusion as used by Howe, and Purves (2005a). The top horizontal line appears to be longer, however, both lines are the same length. B: The Brentano version of the Müller-Lyer illusion (de Grave et al., 2006).



**Table 3**  
Studies Investigating the Developmental Trends of Susceptibility to the Müller-Lyer Illusion.

Study	Sample	Design	Main finding
Cretenoud et al. (2020)	76 participants aged 6–66	Method of adjustment	Weak decrease in magnitude with age, and no interaction between age and context.
Tinker (1938)	35 children aged 9–10, and 164 adults	Method of adjustment	No difference between children and adults.
Dawson et al. (1973)	452 children aged 4–17	2AFC	Illusion's magnitude decreases with age.
Pitner & Anderson (1907)	250 children aged 6–14, and 28 adults	Method of adjustment	Illusion's magnitude decreases with age.
Weintraub et al. (1973)	120 children aged 8–11, and 60 adults	Up-and-down	Illusion's magnitude decreases with age.
Brosvic et al. (2002)	140 participants aged 3–20	Same-different	Illusion's magnitude decreases with age.
Pollack (1963)	60 children aged 8–12	2AFC	Illusion's magnitude decreases with age.
Pollack (1964)	96 children aged 8–11	2AFC	The illusion decreases with age in simultaneous presentation, but when the parts of the illusion were presented successively the illusion's magnitude increased with age.
Pollack (1970)	120 children aged 9–14, and 20 adults	2AFC	Susceptibility decreases with age when the stimulus is black and white, but no age trend is observed when the illusion is presented in colour.
Barclay & Comalli (1970)	20 children aged 8–10, and 20 adults	Same-different	Illusion's magnitude decreases with age.
Hanley & Zerbolio (1965)	1422 children aged 3–12, and 202 adults	Up-and-down	Increase and then decrease with age.
Girgus et al. (1975)	120 children aged 6–11, and 40 adults	Method of adjustment	Illusion's magnitude decreases with age.
Houghton & Tabachnick (1979)	48 boys aged 6–9	Method of adjustment	Illusion's magnitude decreases with age.
Porac & Coren (1981)	688 observers aged 5–70	Variation of the 2AFC	Illusion's magnitude decreases with age.
Binet (1985)	40 children aged 9–12 years of age	Same-different	Illusion's magnitude decreases with age.
Pathak & Joshi (1986)	350 observers aged 9–26 years	2AFC	Illusion's magnitude decreases with age.
Ebert (1976)	50 children aged 6–11 and 50 adults	2AFC	Illusion's magnitude decreases with age.
Ahluwalia (1978)	35 children aged 9–17 and 10 adults	Method of adjustment	Illusion's magnitude decreases with age.
Johnson & Jackson (1974)	72 children aged 6–18	Method of adjustment	Decrease in susceptibility with age but only for the line with arrowheads pointing out.
Rivers (1905)	20 children (ages not specified) and 50 adults	Method of adjustment	Illusion's magnitude decreases with age.
Walters (1942)	1693 children and young adults aged 6–19	Method of adjustment	Illusion's magnitude decreases with age.
Grzeczowski et al. (2017)	144 participants aged 6–81	Method of adjustment	Illusion's magnitude decreases with age.

*Note.* A total of 22 studies on the developmental trajectory of the Müller-Lyer illusion have been included in the review.

adults. Brosvic et al. (2002) and Barclay and Comalli (1970) also showed that susceptibility to the Müller-Lyer decreases with age in children and adolescents aged 3–20 years and 8–10 years, respectively. These studies employed a paradigm in which participants guessed whether the comparison line was longer, shorter, or equal to the target line. Also, using the up-and-down method, Weintraub and colleagues (1973) reported decreasing susceptibility to the illusion between 8 and 11 years of age. Finally, using a variation of the 2AFC method, Porac and Coren (1981) showed decreasing illusion magnitude with age in children and adolescents aged 5–18 years, who in turn were more susceptible to the Müller-Lyer illusion compared to adults.

Nevertheless, as for the Ponzo and Ebbinghaus illusions, variability in stimuli has yielded contrasting developmental trajectories. Employing the 2AFC paradigm, Pollack (1964) showed that the Müller-Lyer illusion decreases in magnitude between 8 and 10 years when all of the illusion's parts are presented simultaneously, however, it increases in magnitude when the different parts (the line and the arrowheads) are presented successively. Pollack argues that when parts of the Müller-Lyer are presented successively, comparisons between the stimulus elements occur over time, drawing upon intellectual functioning and memory. Consequently, older children are more susceptible because they incorporate the stimulus elements together, eliciting the illusion.

Two studies by Tinker (1938) and Hanley and Zerbolio (1965) also report unusual results. In Tinker (1938), using the method of adjustment, children aged 9–10 years and adults did not differ in sensitivity to the Müller-Lyer illusion. This finding is surprising as other studies investigating the Müller-Lyer illusion found a decreasing trend using the method of adjustment (Cretenoud et al., 2020; Girgus et al., 1975; Houghton & Tabachnick, 1979; Pinter & Anderson, 1916). Using an up-and-down task, Hanley and Zerbolio (1965) reported that susceptibility to the illusion initially increases with age, peaking at around 7 years, and then gradually declines in magnitude thereafter. These unusual findings are unlikely to be related to methods, as Weintraub and colleagues (1973) employed the same up-and-down task and obtained opposing results. However, Weintraub and colleagues compared a line with arrowheads to a straight line, while Hanley and Zerbolio used a classic version of the illusion (where both lines have arrowheads). Removing

arrowheads on one of the two lines may have decreased the strength of the illusion.

Despite contrary illusory trends, perception of the Müller-Lyer illusion may take longer to develop to an adult-like level than the Ebbinghaus illusion; Brosvic and colleagues (2002) showed that perception of the Müller-Lyer reaches an adult level of sensitivity around 15 years of age, whereas the Ebbinghaus approaches an adult level around 11 or 12 years (Doherty et al., 2010). Similarly, Pollack (1963) showed that susceptibility to the Müller-Lyer illusion reaches an adult-like level around 14 years of age. The Müller-Lyer longer to reach an adult-like level because it is more cognitively/perceptually demanding than the Ebbinghaus and Ponzo illusions. Indeed, the illusion produces the strongest illusory effects in adults when using the method of adjustment, suggesting that it requires greater cognitive or perceptual abilities which younger children may lack (Sperandio et al., 2023).

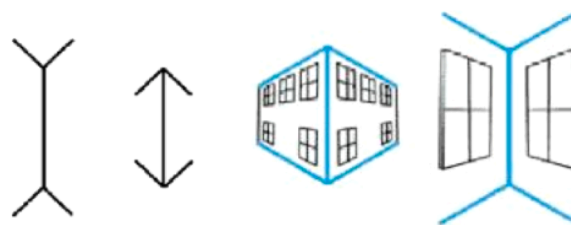
## 5.2. Theoretical explanations

Gregory's (1966) explanation for the Müller-Lyer illusion posits that the line with outwards-facing arrowheads is perceived as a concave corner, while the line with inwards-facing arrowheads is perceived as a convex corner (see Fig. 6 below). The 'concave' corner is perceived as further away compared to the 'convex' corner, hence it is seen as longer. This view does not, however, account for the Brentano version of the illusion. Alternatively, Bermond and Van Heerden (1996) propose that the Müller-Lyer illusion occurs due to imperfections in the human visual system. When viewing the illusion, the human brain calculates 'a weighted mean' of the stimulus' size, leading to an unconscious lengthening of the line with inward arrowheads, and shortening of the line with outward arrowheads. A similar explanation was provided by Howe and Purves (2005), who attributed the Müller-Lyer illusion to a probabilistic strategy that our visual perception employs. When viewing any visual stimulus, size, orientation, and distance are conflated in the retinal image, meaning the stimulus' real-world properties cannot be accurately derived from the retina (Howe & Purves, 2005). Because acting on visual stimuli is crucial for survival, the visual system generates percepts that are based on "the probability distribution of the physical sources of the retinal image", which are sometimes incongruent with the stimulus' actual physical properties (Howe & Purves, 2005, p. 1228). Therefore, the lines constituting the Müller-Lyer illusion may be perceived as different lengths because the visual system inaccurately calculates the probability distributions of the real-world sources of the lines due to the presence of the misleading context of the arrowheads.

Curiously, contrary to most empirical evidence, theories proposed by Gregory (1966), Kaldy and Kovacs (2003), and Doherty et al. (2010) would predict that susceptibility to the Müller-Lyer illusion should increase with age. If the inability to perceive depth cues causes children to be less susceptible to the Ebbinghaus and Ponzo illusions, it should also make them less susceptible to the Müller-Lyer illusion. Similarly, if children's ability to visually integrate context is immature (as proposed by Kaldy and Kovacs, 2003), children should be less susceptible to the Müller-Lyer illusion than adults. However, results reported by the majority of studies suggest that susceptibility to the Müller-Lyer illusion is not dependent on depth cues or context integration. If the two lines with arrowheads that constitute the Müller-Lyer illusion are presented next to each other horizontally, rather than parallel (as in Brentano's version, see Fig. 8), there would be no depth cues to rely on. Presenting the illusion in this way tests Gregory's theory of convex and concave corners in a 3D world and Doherty et al.'s (2010) hypotheses on pictorial depth. However, children's performance is still less accurate than adults when the illusion is presented in this form (Barclay & Comalli, 1970; Girus et al., 1975; Hanley & Zerbolio, 1965).

Reduced top-down influences are also an unlikely explanation for increased susceptibility to the Müller-Lyer illusion observed in young children. If younger children are less able to bind together local elements of the illusion, theoretically they should be less susceptible than older children and adults because their length estimates would not be biased by the presence of the arrowheads. It is possible that the distracting elements of the Müller-Lyer illusion are less salient when compared with those in the Ebbinghaus and Ponzo illusions, enabling children to focus on the target line. Alternatively, it could be that the Müller-Lyer illusion is caused by a probabilistic strategy that our visual perception employs (Bermond and Van Heerden, 1996; Howe & Purves, 2005). Younger children's performance on the Müller-Lyer may be less accurate because they do not see how stimulus elements, and their possible physical sources, interact based on their statistical relationships. Children may make more frequent perceptual errors when judging the sizes of the two lines because their visual system is relatively immature, still in the process of development, and has received less extensive tuning from visual experience in comparison with an adult's visual system. As perceptual learning occurs (Sagi, 2011; Sagi & Tanne, 1994), children's susceptibility to the Müller-Lyer illusion may decrease as their visual system receives greater exposure to concave and convex structures in their environment (see Fig. 6). This explanation is supported by evidence that the Müller-Lyer illusion tends to decrease in strength with practice in adults (Dewar, 1967; Lewis, 1908; Predebon, 2006).

As dominant models of perception (see Sagi, 2011 for an overview) have shown that the magnitude of contextual effects (and



**Fig. 6.** The Concave and Convex of the Müller-Lyer Illusion. Note. A classic version of the Müller-Lyer illusion on the left and its version with 3D depth cues (convex on the left and concave on the right; Jennings, 2016).

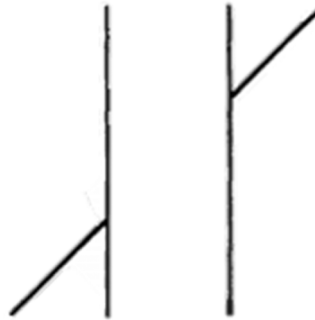


Fig. 7. The Poggendorff Illusion. Note. A version of the Poggendorff illusion as used by Greist-Bousquet and Schiffman (1981). The two oblique lines do not appear to be collinear, when in fact they are.

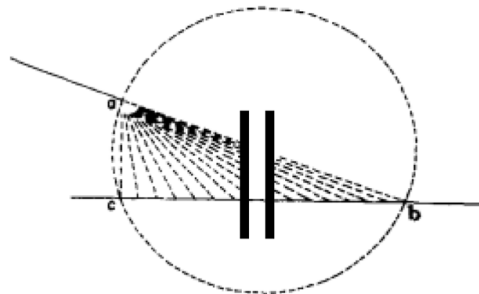


Fig. 8. Pressey's Explanation of the Poggendorff Illusion.

perceptual illusions) may vary with sensory precision, the developing, noisier sensory system may rely more on context/priors. Children's increased susceptibility to the Müller-Lyer illusion may therefore not necessarily point to the development of illusion susceptibility, but rather to the increased noise in their developing sensory systems. Another possibility is that children's performance on the Müller-Lyer illusion may differ because it draws upon different perceptual/neural mechanisms compared with the Ebbinghaus and Ponzo illusion. For example, susceptibility to the Ebbinghaus and Ponzo illusion has been linked to surface thickness of the V1 area (Schwarzopf et al., 2010), while responses in the V1 are consistent with susceptibility to the Müller-Lyer illusion (Ho & Schwarzkopf, 2022). These findings hint that the development of the V1 area affects susceptibility to the Müller-Lyer illusion differently than it does for the Ebbinghaus and Ponzo illusions. However, further research is required to validate this speculative theory.

In summary, most studies indicate that the Müller-Lyer illusion's magnitude decreases as children get older. This developmental trend is opposite to what we have observed for the Ebbinghaus and Ponzo illusions. Furthermore, evidence regarding the Müller-Lyer illusion's developmental trajectory tends to be consistent. This increased level of consistency may be attributed to less variability in stimulus displays, as discussed in more detail below.

### 6. The Poggendorff illusion

Named after Johann Christian Poggendorff, the classic version of the Poggendorff illusion presents the viewer with a structure (usually a rectangle) with lines on each side (see Fig. 8). The illusory effect causes the viewer to inaccurately perceive that the two lines

**Table 4**  
Studies Investigating the Developmental Trends of Susceptibility to the Poggendorff Illusion.

Study	Sample	Design	Main finding
Girgus & Coren (1987)	60 children aged 6–10, 20 adults	Method of production	Illusion's magnitude decreases with age.
Greist-Bousquet et al. (1987)	80 children aged 7–13	Method of production	No difference.
Pressey & Sweeney (1970)	100 children aged 8–14	Method of production	Illusion's magnitude decreases with age.
Leibowitz & Gwozdecki (1967)	321 participants aged 5–80	Method of adjustment	Illusion's magnitude decreases with age.
Spitz et al. (1970)	28 children aged 10 and 28 children aged 15	2AFC	No difference between 10- and 15-year-olds.
Hill (1974)	18 children aged 7 and 10 children aged 14	2AFC	Illusion's magnitude decreases with age.
Tinker (1938)	35 children aged 9–10, and 164 adults	Method of adjustment	Illusion's magnitude decreases with age.
Chouinard et al., (2013)	107 children aged 7–14	Method of adjustment	Illusion's magnitude decreases with age.
Vurpillot (1957)	Children aged 5–12 years old and adults.	Method of adjustment	Illusion's magnitude decreases with age.

Note. A total of 9 studies on the developmental trajectory of the Poggendorff illusion have been included in the review.

are not collinear, when in fact they would join to form a straight line.

### 6.1. Summary of findings

Similar to the Müller-Lyer illusion, the magnitude of the Poggendorff illusion has been found to decrease with age in numerous studies (an overview of all studies on the Poggendorff illusion can be found in Table 4). Using the method of production, Pressey and Sweeney (1970) and Girus and Coren (1987) found that the illusion's magnitude decreases with age (with the illusion still declining at 15 and 22 years respectively). Using the method of adjustment, Vurpillot (1957), Leibowitz and Gwozdecki (1967), Chouinard et al., (2013), and Tinker (1938) found that children aged 5–14 years show increased susceptibility to the Poggendorff illusion compared to adults. Using the 2AFC method, Hill (1974) also found that the illusion's magnitude decreases with age between 7 and 14 years.

However, akin to the previous VIs, evidence concerning the Poggendorff illusion's developmental trajectory is not universally consistent. Using the method of production, Greist-Bousquet and colleagues (1987) found that children aged 7–13 years were equally susceptible to the illusion as adults. Similarly, using a 2AFC method, Spitz and colleagues (1970) found that children aged 9–10 years were as susceptible to the illusion as children aged 15 years.

### 6.2. Theoretical explanations

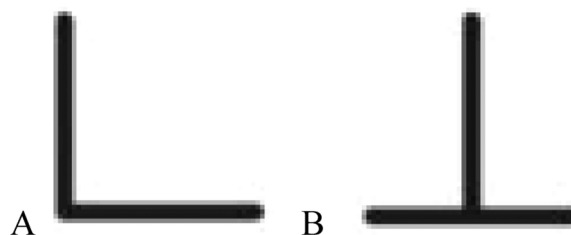
As for the Ebbinghaus, Ponzo, and Müller-Lyer illusions, it has been proposed that the Poggendorff illusion is caused by depth cues (Gilliam, 1971; Spehar & Gilliam, 2002). Although these cues are not strong enough to cause an explicit experience of depth, they may still elicit an illusory effect similar to the Ebbinghaus illusion (Gilliam, 1971). The two oblique lines are perceived as receding horizontal lines in a 3D world, while the gap between them is perceived as a plane normal to the line of sight. Hence, collinearity is not assumed, eliciting the illusory percept. However, in recent experiments where pictorial depth cues were added to both the central rectangle and the background, the illusion's strength decreased in adults (Yildiz et al., 2022a). Therefore, difficulties in perceiving pictorial depth are an unlikely explanation for children's increased susceptibility to the Poggendorff illusion. Another theoretical explanation for the Poggendorff illusion is that the viewer's attention is restricted to a specific region (like a spotlight focusing on the illusion, see Fig. 8 below; Pressey, 1972). When the participant is asked to extend the line in their imagination (so it constitutes a straight line), the participant unconsciously creates multiple lines that are inherently shorter than the 'objective' line. Then, the participant calculates the position of the 'illusory' line based on the mean position of the unconsciously created lines (see Fig. 8). Consequently, the line that is traditionally perceived as the true extension of the line is always below the *true* line.

According to Pressey (1972), younger children are more susceptible to the Poggendorff illusion than older children and adults because they are less visually experienced, resulting in their calculation of the mean extension line deviating further from the true line. Indeed, retinal images are informed by age-related visual experience (Howe & Purves, 2004; Howe et al., 2005). Alternatively, based on Gilliam's (1971) depth processing theory, children may be more susceptible to the Poggendorff illusion than adults because they are unable to perceive pictorial depth to the same extent. This, however, contradicts earlier accounts that the inability to perceive depth cues results in decreased susceptibility to the Ebbinghaus and Ponzo illusions. Finally, the Poggendorff illusion's developmental trajectory cannot be attributed to weaker top-down influences as these should make young children less susceptible, rather than more susceptible. Indeed, Harris et al., (2023) demonstrated that adding a secondary task (reading a clock) that should interfere with perception of the Poggendorff illusion due to increased top-down interference does not affect its strength in adults. Furthermore, development of the visual system may reduce the strength of the illusion as fewer perceptual errors are made and processing becomes more refined with increasing experience (Mallenby, 1976). Regardless of the theoretical explanation, it is clear that children's visual perception mechanisms mature with age, reducing their susceptibility to the Poggendorff illusion.

To summarise, as for the Müller-Lyer illusion, the majority of studies report that the magnitude of the Poggendorff illusion decreases with age, irrespective of methodology. Different cut-off ages could be attributed to differences in stimuli, though most response methods and illusion variants appear to yield similar results.

## 7. The Vertical-Horizontal illusion

The final illusion included in this review is the Vertical-Horizontal illusion (sometimes known as the Horizontal-Vertical illusion).



**Fig. 9.** The Vertical-Horizontal Illusion. Note. The two versions of the Vertical-Horizontal illusion as used by Mamassian and de Montalembert (2010). A is the L version, while B is the inverted T version.

Adolf Fick is often credited as the inventor of this illusion (e.g., Avery & Day, 1969; Wade, 2014), although Edmund Sandford (1898) and Edward Titchener (1901) could be credited for the L version and inverted T version respectively (see Landwehr (2014); see Fig. 9). In its classic versions, two identically long lines are presented horizontally and vertically to create an inverted T or an L. In both presentations, the horizontal line appears to be shorter than the vertical line.

### 7.1. Summary of findings

The developmental trajectory for the Vertical-Horizontal illusion is not yet established (an overview of all studies on the Vertical-Horizontal illusion can be found in Table 5). In early studies using the method of production, Rivers (1905) and Winch (1907) found that children aged 8–14 years decreased in susceptibility with increasing age. Using the method of adjustment, Walters (1942) and Seashore and Williams (1930) report similar trends. However, using the method of adjustment, Tinker (1938) found that children aged 9–12 years were less susceptible to the Vertical-Horizontal illusion than adults (both for the inverted T and the L versions of the illusion), suggesting increased susceptibility with age.

As for the Ponzo illusion, different versions of the Vertical-Horizontal illusion produce contrasting results. Using the 2AFC method, Fraisse and Vautrey (1956) showed that affording participants unlimited time to inspect the inverted T version of the illusion resulted in decreasing sensitivity between 6 and 10 years. However, under the same conditions, the L version of the illusion yields the opposite developmental trajectory. With tachistoscopic presentation (very brief, ~1 s), susceptibility to the L version of the illusion does not increase with age, and susceptibility to the inverted T slightly decreases with age. The differences in developmental trajectories for these illusion variants and methods of presentation can be attributed to two factors. Firstly, when time is unlimited, children may exhibit decisional and response biases (e.g., trying to ‘see through’ the illusion rather than visually discriminating the two lines) or limit their cognitive effort. Indeed, Bressan and Kramer (2021) showed that the magnitude of the Ebbinghaus illusion weakens when response time is unlimited. Secondly, it is possible that different neural mechanisms mediate the perception of the two versions, and that these mature at different rates (Hanley & Zerbolio, 1965).

Using the 2AFC method, Dawson et al. (1973) also reported decreasing magnitude of the Vertical-Horizontal illusion (for both the inverted T and L versions) up to 11 years of age in both Hong Kong and US children. However, using the same method, Fry and Craven (1972) did not find a significant difference between adults and young boys aged 5–14 years. Brosvic et al. (1993) found that susceptibility to the Vertical-Horizontal illusion declines with age between 3 and 10 years. In this study, participants were shown the illusion, asked to memorise it, and then find it amongst comparators which varied in size. Using the same-different method, Brosvic et al. (2002) report that susceptibility to the Vertical-Horizontal illusion declined with age, reaching adult-like susceptibility at around 15 years of age. Finally, Hanley and Zerbolio (1965) showed increasing magnitude with age using an up-and-down design in children aged 3–12 years of age.

### 7.2. Theoretical explanations

A classic explanation of the Vertical-Horizontal illusion is that viewers experience a ‘vertical bias’ – they tend to overestimate vertical lengths compared to horizontal lengths (Jackson & Cormack, 2007; Künnapas (1955)). However, Hahnel-Peeters et al. (2020)

**Table 5**  
Studies Investigating the Developmental Trends of Susceptibility to the Vertical-Horizontal Illusion.

Study	Sample	Design	Main finding
Brosvic et al. (1993)	120 children aged 3–10, and 15 adults	Memorising the stimulus and finding it among comparators	Across all variations of the illusion, the illusions' magnitude decreases with age.
Brosvic et al. (2002)	140 participants aged 3–20	Same-different	Illusion's magnitude decreases with age.
Fry & Craven (1972)	40 boys aged 5–14, and 24 adults	2AFC	No difference.
Winch (1907)	66 boys aged 8–14	Method of production	Illusion's magnitude decreases with age.
Fraisse & Vautrey (1956)	91 children aged 6–10, and 47 adults	2AFC	The magnitude of the L form of the illusion increases with age, while the inverted T shows a slight decrease in magnitude with age.
Tinker (1938)	35 children aged 9–10, and 164 adults	Method of adjustment	Illusion's magnitude increases with age.
Dawson et al. (1973)	452 children aged 4–17	2AFC	Illusion's magnitude increases with age.
Hanley & Zerbolio (1965)	1422 children aged 3–12, and 202 adults	Up-and-down	Illusion's magnitude increases with age.
Rivers (1905)	12 children (age unknown) and 15 adults	Method of production	Illusion's magnitude decreases with age.
Seashore & Williams (1900)	200 children aged 6–15 and 73 adults	Method of adjustment	Illusion's magnitude decreases with age.
Walters (1942)	1693 children and young adults aged 6–19	Method of adjustment	Illusion's magnitude decreases with age.

*Note.* A total of 11 studies on the developmental trajectory of the Vertical-Horizontal illusion have been included in the review.

report that only 1% of variance when estimating vertical versus horizontal lengths in a natural environment is explained by sensitivity to the Vertical-Horizontal illusion. Consequently, these authors suggest that the illusory effect arises as a by-product of multiple mechanisms (e.g., the complexity of the surrounding contexts) that work together to generate this specific perceptual ambiguity, rather than a single general mechanism (also see Jackson et al., 2013).

One possibility is that children are more susceptible to the Vertical-Horizontal illusion than adults because they experience a stronger vertical bias under the age of 9 years (Fayt et al., 1992). Children may experience vertical bias to a greater extent than adults because they are usually much shorter than other people in their environment. Given that many things are ‘out of their reach’, and many of the people in their surroundings are significantly taller than them, their estimations of vertical heights may be biased. Also, young children are visually inexperienced compared with adults, meaning their judgements of vertical lengths may be less accurate. Alternatively, Piaget and Morf (1956, as cited in Brosvic et al., 1993) claimed that children’s increased susceptibility to the Vertical-Horizontal illusion may be due to their inability to process spatial coordinates accurately (spatial estimates in children below the age of eight years are less accurate when compared with older children and adults; Jahoda & McGurk, 1974).

In summary, although most studies show increased susceptibility to the Vertical-Horizontal illusion in children, its developmental trend is not entirely consistent. As for other illusions, future studies should closely examine how differences between methodologies and stimuli variants influence the developmental trajectory.

### 8. Discussion

As shown in this systematic review, susceptibility to VIs changes over the course of children’s development. VIs can be broadly categorised based on whether children’s susceptibility increases (the Ebbinghaus and Ponzo illusions) or decreases (the Müller-Lyer, Poggendorff, and Vertical-Horizontal illusions) with age, and whether susceptibility trends are relatively consistent (the Müller-Lyer and Poggendorff illusions) or inconsistent (the Ebbinghaus, Ponzo, and Vertical-Horizontal illusions). VIs can also be grouped based on whether they are primarily researched using the 2AFC (the Ebbinghaus and Ponzo illusions) or the method of production or adjustment (the Müller-Lyer and Poggendorff illusions).

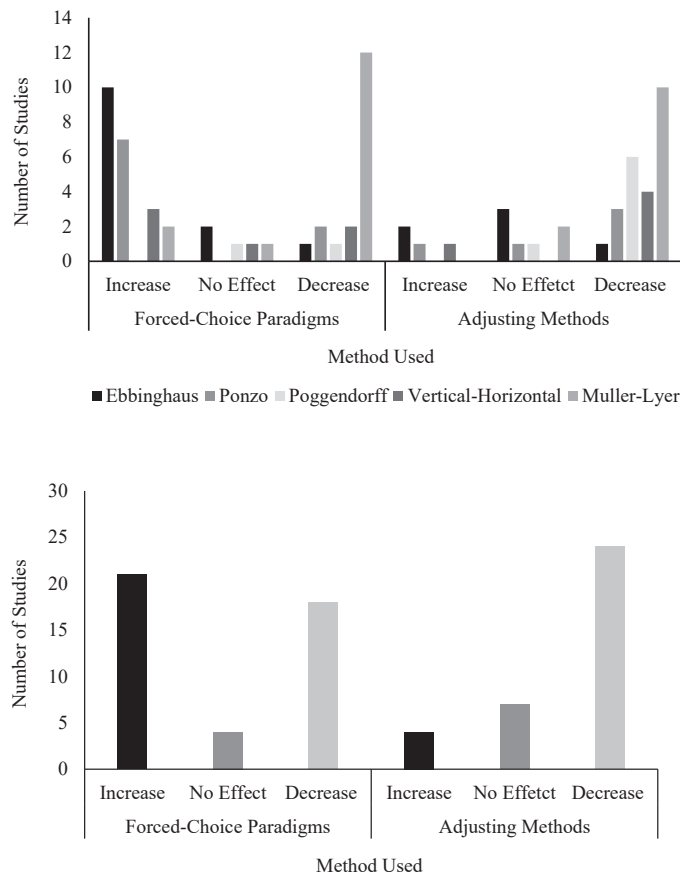


Fig. 10. Developmental Trajectories for Visual Illusion Susceptibility Across Different Methods. Note. For the forced-choice paradigms, 7 trends indicating decreased VI susceptibility with age are assigned to the Müller-Lyer illusion, which has the clearest developmental trajectory of all illusions included in this review.

## 9. Primary and secondary visual illusions

A clear pattern emerges from this review; children's susceptibility increases with age for certain illusions but decreases for others. This dichotomy was identified and discussed by Piaget and his collaborators (Lorden et al., 1979; Pressey, 1974). According to Piaget (1969, as cited in Lorden et al., 1979), primary illusions (type I) decrease in magnitude as children get older, while secondary illusions (type II) increase in magnitude. Thus, the Müller-Lyer, Poggendorff, and Vertical-Horizontal illusions could be categorised as primary illusions. Perception of type I illusions does not rely on intellectual abilities (Pollack, 1964) and their magnitude correlates with chronological age, rather than mental age (whereas type II illusions show an opposite pattern; Clem & Pollack, 1975). This dichotomy between type I and type II illusions is believed to be caused by 'centration' (Piaget, 1961, (1967), as cited in Cretienoud et al., 2020). Centration occurs due to the overestimation of an object present in the centre of the visual field, as compared to its surroundings. Because primary illusions rely on elements' interactions within a single fixation (Flavell, 1963, as cited in Hanley & Zerbolio, 1965), simultaneous comparison of the elements causes the illusions to occur (Clem & Pollack, 1975). Therefore, younger children may make more visual centration compared with older children, causing them to be more susceptible to type I illusions.

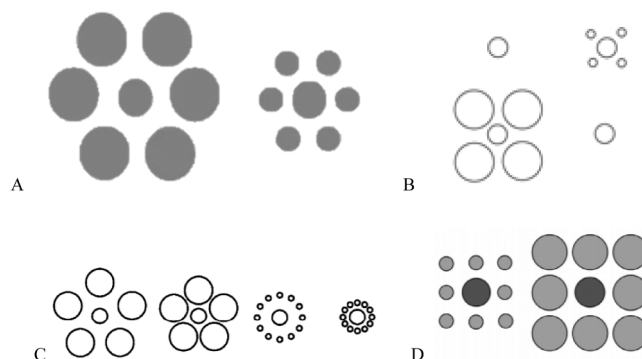
The Ebbinghaus and Ponzo illusions can be categorised as secondary illusions (type II), as they are mostly shown to increase in magnitude as children get older. Piaget (1961, 1963, as cited in Cretienoud et al., 2020) proposed that children increase in susceptibility to type II illusions as their cognitive and visual abilities mature (e.g., depth perception, context integration). Type II illusions rely on active exploration and comparisons between an illusion's elements (arguably the Ebbinghaus and Ponzo illusions cover more of the visual field, and involve more elements than other illusions included in this review; Clem & Pollack, 1975; Hanley & Zerbolio, 1965; Pollack, 1964). These explanations align with theoretical claims that young children are less able to integrate context (Kaldy & Kovacs, 2003) or perceive pictorial depth (Doherty et al., 2010), meaning they are less susceptible to type II VIs.

## 10. Methodological differences

Methodological differences may also influence children's susceptibility to VIs at different ages. Response methods most commonly employed by VI studies include the 2AFC, method of adjustment, method of production, same-different method, and the up-and-down method. The two most frequent methods utilised by studies in this review are the 2AFC ( $n = 43$ ) and the method of adjustment ( $n = 35$ ). These methods account for 80 out of 83 trends (note that some studies report more than one trend per illusion). Therefore, in line with the division made by Kingdom and Prins (2016), we will refer to the 2AFC, same-different, and up-and-down methods as 'forced-choice paradigms', while the method of adjustment and method of production will be referred to as 'adjusting methods' from now on. Adjusting methods typically measure the magnitude of the illusion (how much larger/smaller the target is compared to the reference), while forced-choice paradigms measure the accuracy/discrimination ability to detect physical differences between targets (for example, is the top or the bottom line longer?). Comparing these methods across individual illusions reveals a clear pattern in the literature: forced-choice paradigms usually yield an opposite developmental trajectory compared to adjustment methods (excluding the Müller-Lyer and Poggendorff illusions which produce stable results regardless of methodology; see Figs. 10 and 11 below).

Out of 33 trends for the Ebbinghaus and Ponzo illusions, 20 showed increased susceptibility with age, of which 16 were obtained using forced-choice paradigms (Ebbinghaus  $n = 10$ ; Ponzo  $n = 7$ ). An additional three trends showing increased susceptibility with age were obtained using adjusting methods (two for the Ebbinghaus illusion, and one for the Ponzo illusion), and another was observed using a different method for the Ebbinghaus illusion. For the Vertical-Horizontal illusion, studies employing forced-choice paradigms were more likely to discover increasing susceptibility with age (three studies show increasing magnitude with age, one study shows no difference, and two show decreasing magnitude) compared with adjusting methods that tended to identify decreasing susceptibility with age ( $n = 4$ ), rather than increase ( $n = 1$ ).

Across all illusions studied with forced-choice paradigms ( $n = 45$ ), illusion magnitude increased with age in 22 cases, decreased with age in 18 cases (of which 12 were for the Müller-Lyer illusion, which has the most clearly defined susceptibility trend), and 4 cases showed no significant age effects. Studies employing adjusting methods mostly found decreasing magnitude with age (24 out of 35



**Fig. 11.** The Different Versions of the Ebbinghaus Illusion, Note. Version A, B, C, and D were used by Hadad (2018), Bonadrko and Semenov (2004), Duemmler et al. (2008), and Bremner et al. (2016), respectively.

trends) and just four identified increasing magnitude for the Ebbinghaus ( $n = 2$ ), Ponzo, and Vertical-Horizontal illusions. Slightly more studies using the adjusting methods failed to identify age differences ( $n = 7$ ; of which three were obtained for the Ebbinghaus illusion) compared with the forced-choice paradigms ( $n = 5$ ). These findings strongly suggest that differences in response method may contribute to variability in observed findings concerning VI susceptibility.

A potential reason why illusions like the Ebbinghaus or Ponzo are more frequently researched using forced-choice paradigms is that traditional, noncomputer-based experiments using adjusting methods were harder to create than for illusions like the Müller-Lyer and Poggendorff. For the Müller-Lyer and Poggendorff illusions, study findings are more consistent despite variation in children's response methods – sensitivity to these illusions reliably decreases with age. Across 28 trends for the Müller-Lyer illusion, 23 trends indicated decreasing magnitude with age (forced-choice paradigms – 12 trends, adjusting methods – 10 trends, and other methods – 1 trend), increasing magnitude with age was detected in two cases, (both using forced-choice paradigms), and three cases found no age effects (forced-choice paradigms = 1; adjusting methods = 2). For the Poggendorff illusion, forced-choice paradigms found decreasing susceptibility with age in one experiment, while adjusting methods elicited decreasing susceptibility with age in six experiments. These findings suggest that the Müller-Lyer illusion is robust to variations in response method and reliably decreases in magnitude with age. This may also be true for the Poggendorff illusion, although this illusion has only been studied twice using the forced-choice paradigms (with one showing no effect of age).

We also observed that the distribution of methods is uneven between illusions. Illusions producing mostly an increasing trend in susceptibility (the Ebbinghaus and Ponzo illusions) are more commonly researched using forced-choice paradigms ( $n = 22$ ) than adjusting methods ( $n = 11$ ). Conversely, VIs that are often shown to decrease in magnitude with age (the Müller-Lyer and Poggendorff illusions) are mostly researched using adjusting methods ( $n = 19$ ) rather than forced-choice paradigms ( $n = 17$ ), although both illusions show a much more clearly defined susceptibility trend compared to the Ebbinghaus and Ponzo illusions.

Theoretically, if one's susceptibility to an illusion is reduced or increased, the same trend should remain constant despite variations in response method. However, the existing literature investigating VIs clearly demonstrates that this is not the case. Differences between various methods are not well understood as very few studies have examined children's illusion susceptibility using more than one method. In a notable exception, Manning et al. (2017) examined susceptibility to the Ebbinghaus and Müller-Lyer illusions in children aged 6–14 years using the same-different method, method of adjustment, and forced-choice paradigms with a roving pedestal (for further details, see Morgan et al., 2013). Their results showed that children did not differ in their susceptibility across different methods. It is, however, important to highlight that children's performance was not compared across different ages, therefore it is unclear whether younger children differed in their performance compared with older children when responding to different methods and/or illusions. In another study, Hadad (2018) compared susceptibility to the Ebbinghaus illusion when using forced-choice paradigms and method of adjustment in children aged 4–8 years and adults. They observed that children were more susceptible to the Ebbinghaus illusion than adults using the method of adjustment, but not forced-choice paradigms.

Finally, the two categories of methods differ in terms of their requirements and outcomes. Adjusting methods require participants to 'match' the target (e.g., the top line in the Ponzo illusion) with a constant reference (e.g., the bottom line of the Ponzo illusion). The outcome of this 'matching' is the magnitude of the perceived illusion, i.e., the physical difference in size between the target and the constant reference. Forced-choice paradigms, on the other hand, measure the ability to discriminate between two sizes (e.g., the two inner circles in the Ebbinghaus illusion). The outcome of this is the proportion of correctly reported differences. Therefore, observed differences in susceptibility between children and adults for some illusions (especially the Ebbinghaus and Ponzo illusion) might be attributable to the different measurements employed and the contrasting challenges they present for children. Further research is required to investigate interactive relationships between different VIs, response methods, and chronological age.

### 10.1. Cognitive biases and strategy use

Studies that utilise adjusting methods and forced-choice paradigms may report different age trends because these tasks draw upon different cognitive mechanisms and biases. There are two key cognitive biases that are relevant to studying VIs; response bias and decisional bias (Morgan et al., 2013). The response bias occurs when one type of answer is systematically preferred over others, despite the stimulus condition (Wetzel et al., 2016). Decisional bias is the strategy adopted by a participant when unsure of their judgements in difficult tasks (Morgan et al., 2013).

Some researchers have argued that forced-choice paradigms may be inadequate for measuring children's susceptibility to the Ebbinghaus and Ponzo illusions as they are prone to response and decisional biases (Morgan et al., 2013; Kingdom & Prins, 2016). As forced-choice paradigms usually involve a larger number of trials than adjusting methods, repeated exposure to the same illusion may lead to a greater overreliance on perceptual biases due to boredom, tiredness, or perseveration. Furthermore, children may differ from adults in terms of their expectations about the properties of targets (i.e., their threshold for perceiving targets as identical in size may be lower). Finally, children may intentionally or unintentionally adopt a different set of criteria on how to respond to the task (Kingdom & Prins, 2016), which may lead to the appearance of differences in VI susceptibility in comparison with adults. In line with this, children below the age of 10 years show poorer performance on computerised assessments of response bias due to reduced motivation and less effort invested into the task (Courtney et al., 2003). For example, Thelen and Watt (2010) observed that children up to 6 years of age exhibit a tendency to perseverate on the target circle with larger surroundings, regardless of the size of the inner circle. When this effect was controlled for, no differences between children and adults were identified in their susceptibility to the Ebbinghaus illusion. A similar bias could explain why Doherty et al. (2010) found that children aged 4–6 years were more sensitive to very small changes (2%) in the Ebbinghaus illusion than adults. Here, children only performed at chance when the display of the illusion was congruent with its illusory effect (i.e., the target circle that is classically perceived as smaller, was in fact physically



smaller). For example, children's task might be to always point towards the larger, inner circle. Therefore, in an experiment where in most cases, the 'perceived as larger' circle is physically larger (except when the smaller circle is congruent with the illusion, see above), such display would cause children to appear less susceptible (if they rely on a strategy that involves selecting the large surroundings only), as they would correctly respond in the majority of trials. The findings of [Bremner et al. \(2016\)](#), [Imada et al. \(2013\)](#), [Schulze et al. \(2022\)](#), and [Küttük et al., \(2023\)](#) could also be subject to similar biases.

There are two explanations for children's perseverative responses in studies of the Ebbinghaus illusion. Firstly, younger children (e.g., 4–6 years of age) may try to limit the cognitive effort they expend during the task as visual discrimination of small size differences in VIs over many trials can be fatiguing ([Courtney et al., 2003](#)). Therefore, younger children – who tend to have more limited attention spans than adults ([Betts et al., 2006](#)) – may at some point start to rely on a response bias strategy rather than visual discrimination. Secondly, children may perseverate on stimuli with larger surroundings due to their preference for more visually stimulating arrays ([Braine & Shanks, 1965](#)). Thus, in the Ebbinghaus illusion, children might simply prefer larger surroundings as opposed to having a better ability to discriminate size differences. Consequently, with age-related improvements in general fluid intelligence and sustained attention ([Betts et al., 2006](#); [Fry & Hale, 2000](#)), children's performance may become more adult-like because they are able to stay "on-task" for longer (yielding a more valid measure of their visual perception, rather than response strategy use).

For the Ponzo illusion, opportunities for strategy use are perhaps more limited. Most studies employing forced-choice paradigms only manipulate the length of the line that is perceived as further away. As the 'closer' line is presented as both shorter and longer, perseverating to only one type of answer (i.e., repeatedly stating the line is shorter or longer) would result in chance-level performance. However, if children answer correctly when lines are clearly different lengths, their scores would increase, causing them to appear less susceptible to the VI. This could potentially explain why researchers using forced-choice paradigms identified increasing Ponzo illusion susceptibility with age.

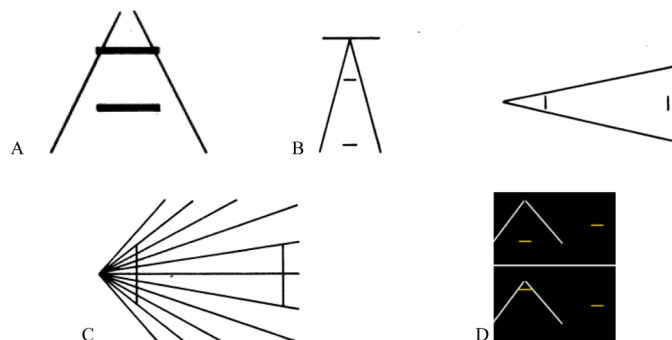
Finally, it may be easier for some children to respond accurately via the method of adjustment than forced-choice paradigms because it allows the participant to indefinitely increase or decrease the target to find the closest match. This response method may favour older participants who are more cognitively skilled, perhaps explaining why most studies that employ adjusting methods have identified decreasing illusion magnitude with increasing age. For example, younger children are less able to attend to multiple objects simultaneously compared to older children and adults ([Dye & Bavelier, 2010](#)). Also, visual search abilities are shown to develop with age, as children are slower to detect targets than adults ([Donnelly et al., 2007](#)). Furthermore, children's sustained attention increases significantly between the ages of five and nine years (when susceptibility to some illusions, like Ebbinghaus or Ponzo, starts to appear more adult-like; [Betts et al., 2006](#)). However, the method of adjustment requires more effort, as participants are required to manipulate sizes, rather than make simple visual discriminations as in forced-choice paradigms ([Courtney et al., 2003](#)).

As more studies comparing response methods emerge, current beliefs that children are less or more susceptible to certain illusions may be called into question (especially for the Ebbinghaus and Ponzo illusions). Methodological differences require further investigation to establish whether age-related differences are in fact due to perceptual differences between children and adults, or cognitive and response biases associated with specific tasks.

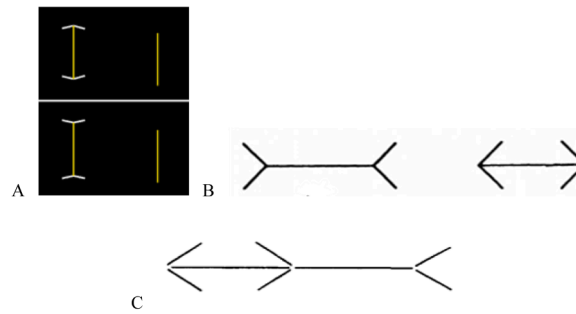
## 10.2. Variations in stimuli

The lack of reliable developmental trends for certain VIs may be attributed to variations in stimuli presented to participants. This is especially relevant to the Ebbinghaus and Ponzo illusions, which allow for more variations compared to the Vertical-Horizontal and Poggendorff illusions. For illustration, different versions of the Ebbinghaus, Ponzo, and Müller-Lyer illusions are presented in [Fig. 11](#), [Fig. 12](#), and [Fig. 13](#) respectively. Notably, while variations of the Ebbinghaus and Ponzo illusion differ markedly in their appearance, variants of the Müller-Lyer illusion are relatively more consistent (perhaps explaining why developmental findings associated with this illusion are more reliable).

Contrasting result patterns associated with different illusion variants have been noted in the developmental literature. Doherty and colleagues (2010) argue that certain versions of the Ebbinghaus illusion could lead to erroneous findings. If the surroundings are aligned as a tight ring around the target circle, such a display may cause young children (aged approximately 4–6 years) to confound



**Fig. 12.** The Different Versions of the Ponzo illusion, Note. Versions A, B, C, and D, as used in studies by [Brislin \(1974\)](#), [Hanley and Zerbolio \(1965\)](#), [Leibowitz and Judisch \(1967\)](#), and [Cretenoud et al. \(2020\)](#), respectively.



**Fig. 13.** The Different Versions of the Müller-Lyer illusion, Note. Versions A, B, and C as used by [Cretenoud et al. \(2020\)](#), [Hanley and Zerbolio \(1965\)](#), and [Barclay and Comalli \(1970\)](#), respectively.

the separation between targets and the surrounding circles. For the Ponzo illusion, differences in orientation ([Hanley & Zerbolio, 1965](#)) or complexity ([Pressey, 1974](#)) can cause different susceptibility trends, leading researchers to propose that illusion variants are subserved by distinct perceptual mechanisms ([Greist-Bousquet et al., 1987](#)). Variations in stimuli may also cause differences in illusion complexity, with more perceptually demanding displays (e.g., with more explicit depth) tapping into more sophisticated perceptual mechanisms (e.g., top-down influences) or eliciting these to different extents. In fact, [Cretenoud and colleagues \(2020\)](#) demonstrated that varying the complexity of the Ponzo and Müller-Lyer illusions results in different developmental trajectories and illusion magnitudes. Such differences in stimuli could also explain why studies identify different age thresholds at which children attain adult-like performance, highlighting the need for further research into stimuli variability.

A more philosophical issue is the question of how we should define each particular illusion. For example, what *really* constitutes the Ebbinghaus illusion? Are the circles an essential part of the illusion, or could triangles or squares be used instead? Should the surrounding circles be presented in a tight ring around the middle circle or at an equal distance from the target irrespective of their size? Or does the term ‘Ebbinghaus illusion’ refer to its illusory effect (i.e., everything that causes illusory enlargement/shrinkage of a stimulus based on its surroundings)? Given that different studies present the same illusion in various ways, future researchers should carefully consider their findings and claims that certain VIs increase or decrease with age, as their reported findings may be unique for their version of an illusion.

## 11. Recommendations for future research

As highlighted throughout this systematic review, methodological differences are a likely candidate for explaining contradictory findings across studies investigating developmental trajectories for VIs. Therefore, an important objective for future research is to directly assess whether different response methods (e.g., adjusting methods or forced-choice paradigms) consistently yield opposite developmental trends. It would also be beneficial for future research to examine how children respond to different versions of the same illusion, varying their orientations and complexity. This approach will enable researchers to identify whether certain susceptibility trends are illusion-specific, or whether multiple illusions share common features, thus advancing understanding of their underlying cognitive mechanisms (for a recent example, see [Cretenoud et al., 2020](#)). Both issues should be investigated with particular attention to gender differences, as these have also been noted to affect susceptibility to VIs (e.g., [Miller, 2001](#)).

Although researchers have extensively investigated how saccades (quick and simultaneous movement of both eyes in the same direction, [Kaiser & Lappe, 2004](#)) are biased by different VIs (e.g., Müller-Lyer illusion: [Bruno et al., 2010](#); Poggendorff illusion: [Melmoth et al., 2015](#)), eye-tracking has been absent from developmental research on VIs to date. The use of eye-tracking could advance understanding of several interesting topics. Firstly, eye-tracking could be used to test the assumption that children sometimes perseverate to the larger surroundings in the Ebbinghaus illusion ([Thelen & Watt, 2010](#)). Based on their fixation patterns, it would be possible to determine whether they actually make visual comparisons between targets, or instead employ a less cognitively taxing response strategy. Secondly, eye-tracking could reveal whether differences between children’s and adults’ susceptibility to VIs can be explained by differences in their oculo-motor activity and test Piaget’s theory of centration (e.g., whether younger children make fewer ‘centrations’ compared with older children and adults). Thirdly, eye-tracking would provide interesting insight into the role of top-down and bottom-up influences during the perception of VIs. For example, when inspecting VI stimuli, children may be increasingly drawn to salient features of images and pay less attention to context, thus exhibiting stronger bottom-up influences ([Açik et al., 2010](#); [Donnelly et al., 2007](#)).

## 12. Conclusions

The present review has revealed that children’s susceptibility to illusions develops over time, taking many years to reach adult-like maturity. Crucially, we observed that developmental trajectories differ between different illusions, response methods, and stimuli variations. The balance of evidence indicates that children decrease in their susceptibility to the Müller-Lyer, Poggendorff, and Vertical-Horizontal illusions as they get older, but increase in their susceptibility to the Ebbinghaus and Ponzo illusions with age. Extant literature has yet to pinpoint whether these changes occur due to the development of perceptual, neural, or cognitive

mechanisms. However, it is vital to acknowledge that methodological variability may causally contribute to heterogeneity in findings across studies, and even yield opposing developmental trajectories for the same illusion. This is, perhaps, the key issue that future research ought to address in order to advance understanding of how children perceive and react to VIs. Future research is also necessary to explain why children are more or less susceptible than adults to specific illusions, and whether differences are simply an artefact of experimental design choices.

## Funding

No funding was obtained to support this research.

## CRediT authorship contribution statement

Radoslaw Wincza performed the systematic search and wrote the systematic review. Jerome Fenton-Romdhani performed the systematic search alongside Radoslaw Wincza. Sally Linkenauger, Calum Hartley, and Trevor Crawford supervised the project, and provided theoretical feedback.

## Declaration of Competing Interest

Wincza declares that he has no conflict of interest. Hartley declares that he has no conflict of interest. Fenton-Romdhani declares that he has no conflict of interest. Linkenauger declares that she has no conflict of interest. Crawford declares that he has no conflict of interest.

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