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**The relationships between urbanicity, general cognitive ability, and susceptibility to the
Ebbinghaus illusion**

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Abstract

Previous studies have shown that, in samples of non-Western observers, susceptibility to the Ebbinghaus illusion is stronger in urban than rural dwellers. While such relationship between illusion strength and urbanicity has often been ascribed to external factors (such as the visual impact of the environment), the present study explored the possibility that it is instead mediated by general cognitive ability, an internal factor. We recruited a sample of remote Namibians who varied in their level of urbanicity, and measured their susceptibility to the Ebbinghaus illusion, their levels of education and literacy, and their general cognitive ability. The results showed that urbanicity was related to Ebbinghaus susceptibility, and that general cognitive ability, literacy and education did not mediate this effect, which is reassuring with regard to the findings of previous studies that did not control for these variables. However, we found robust relationships between urbanicity, on the one hand, and cognitive ability, education and literacy, on the other, which advocates for careful consideration of the impact of the latter variables in studies about the cognitive effects of urban environments.

1. Introduction

As early as the beginning of the 20th century, Rivers explored the possibility of cross-cultural differences in perception. He observed that the Todas, a remote people living in the Indian subcontinent, were massively less susceptible to the Müller-Lyer size-contrast illusion than Western individuals (Rivers, 1905). In recent years, similar results were documented with remote populations from Namibia, Cameroon or Brazil, using the Ebbinghaus illusion, a seminal size-contrast illusion where irrelevant peripheral inducers affect the perceived size of a central target (De Fockert et al., 2007; Köster et al., 2018; Mavridis et al., 2020). An increasing body of evidence suggests that living in urban environments, or even simple exposure to urban environments (Caparos et al., 2012), plays an important role in driving these cross-cultural differences. For instance, in Namibia and in Cameroon, urban dwellers systematically showed greater susceptibility to the Ebbinghaus illusion than their rural counterparts (Bremner et al., 2016; Köster et al., 2018; Mavridis et al., 2020) to the extent that, in one study, urban Namibians and Londoners showed similar susceptibility to the illusion (Caparos et al., 2012).

The relationship between urbanicity and susceptibility to the Ebbinghaus illusion may be ascribed to attentional effects. Converging evidence suggests that urban environments exert perceptual and cognitive load due to the multiple stimuli they afford (noises, movements, multitasking), which would then increase physiological arousal and foster defocused attention (Linnell et al., 2013, 2014, 2020). This, in turn, would reduce the ability to ignore irrelevant contextual information when processing a target. Another explanatory account for the effect of urban environments is the 'carpentered world' hypothesis, whereby exposure to carpentered artefacts would increase the sensitivity to abstract geometric shapes (Segall et al., 1966). Finally, one can mention the visual clutter hypothesis (Miyamoto et al., 2006), suggesting that physically more complex (or visually loaded) environments would

promote greater attention to contextual elements (Miyamoto et al., 2006), and this would increase the susceptibility to contrast illusions. The explanatory accounts mentioned here have in common that they appeal to the impact of the environment on visual perception.

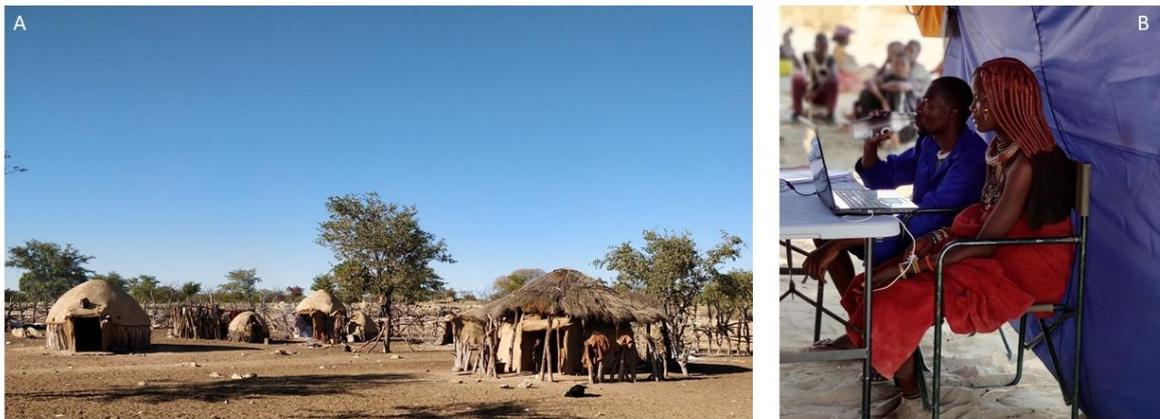
The primary objective of this study was to investigate an alternative (or complementary) hypothesis, that has not been considered previously. Specifically, we aimed to assess whether differences in general cognitive ability – which refers to a broad underlying factor that influences overall performance across various tasks, in terms of processing speed, working memory, or problem solving (Rypma et al., 2006; Demetriou et al., 2002) – could account for the relationship between urbanicity and susceptibility to the Ebbinghaus illusion. Consistent with this idea, recent findings indicate that general cognitive ability may be linked to low-level perception in general (Melnick et al., 2013) and to the Ebbinghaus illusion in particular (De Fockert & Wu, 2009). The relationship between cognitive ability and susceptibility to the Ebbinghaus illusion may be mediated by response latencies. Specifically, given that higher cognitive ability is linked to higher processing speed (Rypma et al., 2006), it may translate into lower inspection time and stronger susceptibility to the Ebbinghaus illusion (Bressan & Kramer, 2021). While cognitive ability has biological underpinnings (Nisbett, 2012), it is also driven by environmental factors, and notably by education through schooling (Peng & Kievit, 2020). Although in previous cross-cultural studies non-Western participants had received no or little schooling (e.g., De Fockert et al., 2007; Caparos et al., 2012), urban environments are nevertheless prone to afford education in informal ways (Carragher et al., 1985;), through their richness in both physical stimuli (objects, shops, services, bars) and social stimuli (individuals coming from more varied cultural and ethnic backgrounds). This, in turn, may increase general cognitive ability, regardless of the absence of schooling. Accordingly, recent findings have shown that logico-mathematical training interventions

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benefited urban dwellers more than their rural counterparts, even in the absence of any schooling (Boissin et al., 2024).

The present study examined whether the relationship between urbanicity and susceptibility to the Ebbinghaus illusion previously observed in non-Western samples (Bremner et al., 2016; Caparos et al., 2012; Köster et al., 2018; Mavridis et al., 2020) might be underpinned by general cognitive ability. To this end, we recruited a sample of Himba participants, a people from Northern Namibia (Africa) who has previously been shown to be less susceptible to the Ebbinghaus illusion than Westerners (Bremner et al., 2016; De Fockert et al., 2007; Caparos et al., 2012). The Himba are semi-nomadic herders with limited exposure to western culture, including limited schooling and low levels of industrialization. They live in small, collectivist villages (20 to 40 adults; Figure 1), speak Otjihimba (a dialect of the Otjiherero language) and do not use written language (Trémolière et al., 2022) or monetary exchanges (Cameron, 2013).

Figure 1. Typical Himba village (A) and a Himba woman participating in the study (B).



Although in the present study the Himba participants all lived in traditional villages, they differed in terms of their level of urbanicity, or “urban tropism”, which we assessed using the reported number of recent visits to the local town of Opuwo (Kaokoland, ~30 000 inhabitants; Mwinga et al., 2022) and a set of indicators of urban permeability (wearing

traditional vs. modern/urban outfit, possession of mobile phone, reported subjective appeal for the local town, attitudes towards preserving the traditional non-urban way of life). These indicators were chosen following previous observations of large individual differences in the Himba population and discussions with our local research assistants. We note that, in this study, urbanicity was operationalised in a unique way, which sets it apart from previous studies; urbanicity did not appeal to rural/urban dwelling, but rather to the overall tropism towards the urban world, measured using a combination of behavioural and attitudinal indices.

Given that most Himba are either illiterate or have very low levels of literacy, we assessed individual differences in general cognitive ability using a set of tasks that do not require reading, namely, a task assessing numerical ability (using simple mental calculations; Grégoire et al., 2003), a forward digit-span task (oral repetition of orally-presented 3-, 4-, and 5-digit sequences; Blanchette et al., 2018), and an adapted version of the WAIS matrices task (using 8 items of the original task; Wechsler, 2008). These tasks were chosen following pilot testing during a previous field trip to Namibia, which showed that (1) performance varied within the sample and that (2) the tasks intercorrelated, suggesting that they all measured a common underlying *g* factor. Given the known links between general cognitive ability, on the one hand, and schooling and literacy, on the other (Peng & Kievit, 2020), we also assessed the impact of the latter two variables.

The specific objectives of this study were threefold. First, we aimed to replicate the finding that Himba observers are less susceptible to the Ebbinghaus illusion than Western observers (who consisted of French participants in the present study; De Fockert et al., 2007). Second, we wished to replicate the positive relationship between urbanicity and illusion strength within the Himba sample (Caparos et al., 2012). Third, we aimed to examine the

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possible mediating role of general cognitive ability in the latter relationship. Related to this third aim, we also explored the role of response latencies.

2. Method

2.1 Participants

131 Himba adults (65 females; mean age 30.5 years, range 17-65 years; 93 Himba never went to school, 38 Himba went to school for a mean number of 4.5 years, range one to nine years) were recruited in two villages located in the vicinity of Opuwo, in November 2022. Sample size was not pre-determined. We tested as many participants as possible during our limited testing window (i.e., during the 20 days that we spent on the field).

All the Himba participants were native speakers of Otjihimba. In the sample, a majority of the participants could not read or write (73 participants), and a minority had some level of literacy (54 participants; see below for details about evaluation of literacy). To our knowledge, none of the participants had prior experience with experimental research. It is important to note that there is some uncertainty regarding the age of some of the participants, as it is culturally rare to track count of age. When necessary, we relied on the research assistant to provide an estimated assessment of the participant's age.

The French comparison sample consisted of 121 native French speakers (65 females; mean age 26.1 years, range 17-59 years) recruited in greater Paris, using social media and word of mouth, by three French research assistants. Sample size was pre-determined, to approximately equate the number of Himba participants. The French participants were not compensated for their time. The Ebbinghaus-illusion data of eight of them were lost due to computer failure during the experimental session.

2.2 Stimuli and procedure

The participants performed a number of tasks as part of a large project aiming to explore numerical cognition and perception in the Himba population. The data related to the other tasks are reported in separate publications (the full set of raw data can be found here: <https://osf.io/m5vkt>). The experimental tasks were computer-based and presented using E-Prime 3.0 (Schneider, Eschman, & Zuccolotto, 2002), on a 14-inch laptop screen, which was placed at a viewing distance of approximately 60 cm. In Namibia, instructions were given orally with the help of a research assistant, who was fluent in both English and Otjijimba, and who was naive to the purposes of the study. All experiments were conducted on an outdoor table, in a shaded area. Participants were compensated with a set of four gift items, namely, maize meal, sugar, vaseline, and soap (the total value of the items was ~5 euros).

2.2.1 Ebbinghaus Illusion

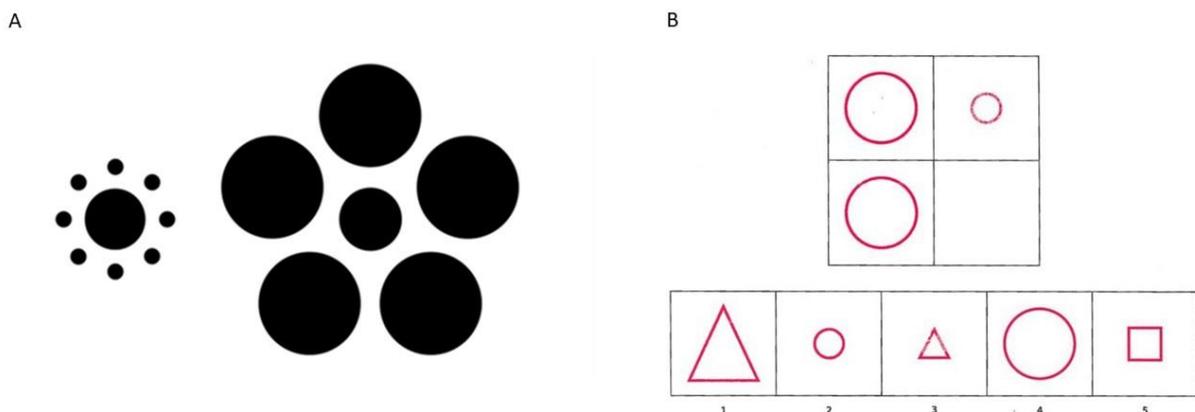
On each trial, two target circles were presented along the horizontal midline of the display, at equal distance (5.5° of visual angle) from its centre (see Figure 2A). One target, always measuring 2.6° in diameter, was surrounded by small inducers (each measuring 0.7° in diameter). The other target, measuring from 2.4° to 3.8° in diameter (in 0.2° steps, creating eight size conditions), was surrounded by large inducers (each measuring 4.4° in diameter). The two targets occurred equally often on each side of the display. Participants decided which target was the largest by pressing the left or right key of a two-key response pad. The display remained until a response was given.

There was one condition where the large-inducer target was smaller than the small-inducer target. In this condition, the illusion reinforced the correct response. There was one condition where there was no correct response; both targets had the same size and the illusion should lead to choosing the small-inducer target. These two trials were used as control trials (see below). There were six misleading conditions where the large-inducer target was larger than the small-inducer target. This asymmetry of target differences in the stimulus set was

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implemented to avoid a large number of redundant conditions (large inducers never produce the illusion of a larger target), and also meant that the median condition in the range did not present veridically equal targets. A block of eight practice trials was first administered where the two targets were not surrounded by inducers. After training, participants were presented with a block of 16 test trials (two trials for each of the eight target-size configurations, presented in a randomized order; see the full set of stimuli in the Supplementary Material, <https://osf.io/m5vkt>). Four Himba participants did not perform the task due to an early withdrawal from the study. In addition, we only analysed the data of participants who had given at least three or four “small-inducer” responses on the four control trials, leading to the exclusion of 15 Himba participants and two French participants. The final sample consisted of 108 Himba participants and 109 French participants. For each participant, we computed the mean percentage of errors for the misleading trials, where a higher percentage indicates a stronger susceptibility to the illusion. We also computed the mean response latency for these trials.

Figure 2. Illustration of one stimulus used (A) in the Ebbinghaus illusion task and (B) in the matrices task.



(A) The figure represents one of the test displays used in the Ebbinghaus illusion, containing two target circles surrounded, respectively, by small and large inducers (in this example,

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while the small-inducer target appears to be bigger due to the illusion, in reality the large-inducer target is bigger). (B) The figure represents one problem from the matrices task, which consists here of an incomplete four-item matrix (top), and five choice items, among which one is chosen to complete the matrix (bottom; in this example, the correct response is the second item from the left).

2.2.2 General Cognitive Ability

Three tasks were used to index general cognitive ability: a numerical ability task, a forward digit-span task, and a matrices task. Given that cross-cultural comparisons between Himba and French participants were neither appropriate nor relevant to the purposes of the study, the tasks described below were performed only by the Himba participants, and not by the French participants.

2.2.2.1 Numerical ability task. The participants had to solve twelve simple numerical problems (adapted from Grégoire et al., 2003). Four of them were numerical comparisons (“Between these two numbers which one is larger?”; “2 and 6”; “13 and 7”; “59 and 73”; “109 and 700”), and eight of them were mental calculations (How much is “4 + 3”; “15 + 12”; “9 – 6”; “14 – 9”; “3 x 2”; “2 x 6”; “Laure has 9 bracelets. She gives away 3 to Caroline and 2 to Annie. After giving the bracelets away, how many has Laure left?”; “You have 14 pumpkins. If you give me half of your pumpkins, how many pumpkins do you still have?”). The problems were spoken orally by the research assistant in Otjihimba. The participants gave their responses orally, which were recorded by the research assistant. For each participant, we computed the percentage of correct responses among the twelve numerical problems. Note that these problems had been pilot-tested during a previous field-trip in Namibia.

2.2.2.2 Digit-span task. The participants heard blocks of 2-, 3-, 4-, and 5-digit sequences of digits (randomly selected amongst the digits 1 to 9). There were three sequences in each block

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(i.e., a total of 12 trials in the task). The sequences were spoken orally by the research assistant, at the approximate rate of one digit per second. When a sequence ended, participants repeated the entire series out loud, in the order of presentation. Before each block, participants were told how many digits they would have to listen to and recall. Experimental blocks proceeded with incremental difficulty. Research assistants typed the participants' responses using the computer keyboard (any forgotten digit was replaced by '0'). The two-digit trials (i.e., the first three trials) were used as practice and were not used to compute performance. A correct response consisted in reporting the whole sequence of digits in the correct order. For each participant, we computed the overall percentage of correct responses to the nine test trials (i.e., to the three-, four-, and five-digit trials).

2.2.2.3 Matrices task. We used an adapted version of the WAIS matrices task. On each trial, participants were presented with a set of items – the matrix – from which one item was missing (see Figure 2B). Participants chose, among five items at the bottom of the screen, which one should complete the matrix. A pilot testing was run during a previous field trip to Namibia, in October 2021, using the 28 problems of the full WAIS matrices task (unpublished data). This pilot testing allowed us to select 8 problems for which there was sufficient interindividual variability in accuracy (i.e., with neither a floor nor a ceiling performance). These items were used to create the version employed in the present study (the eight problems that we used are presented in Supplementary Material, <https://osf.io/m5vkt>). For each participant, we computed the percentage of correct responses to the eight problems.

2.2.3 Questionnaire

Participants responded to a number of socio-demographic questions. The Himba participants were asked the questions orally by the research assistant, who recorded their answers using the laptop keyboard. French participants typed in their response autonomously.

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Relevant questions in the questionnaire for the purpose of this study are age and number of years of formal schooling (from “0” to “9 or more”).

In addition, for Himba participants, literacy was evaluated using three questions. First, participants self-rated their level of literacy (“Can you read and write? (0) Not at all, (1) a little, (2) quite well, (3) very well”). Then, participants were asked to read orally two sets of sentences presented on the computer screen. The first set was presented in English, the official language of Namibia (it read: “I am Himba. I live in Namibia, in the Kaokoland. It is raining today.”), and the second one was presented in Otjihimba, the mother tongue of the participants (it read: “Matuundju ombura. Ozongombe ozorohepero kovahimba”, which translates as “We are waiting for the rain. Cattle is important for Himba people”). For each set of sentences, the research assistant gave an evaluation of the participant’s reading proficiency (“Could the participant read the sentences? (0) Not at all, (1) a little, (2) quite well, (3) very well”). A literacy score, which ranged from 0 to 3, was computed for each participant by averaging the responses to the three literacy items.

We also assessed the Himba’s recent visits to the local town of Opuwo, used here as a proxy of the industrialised/urban world. They estimated how many times they had been there during the last year (from 0 to 10+; Caparos et al., 2012).

Finally, we assessed participants’ tropism towards the industrialised/urban world using four indicators (the possible scores for each indicator are shown into parentheses). First, we recorded whether each participant owned a phone (no = 0; yes = 1) and wore an urban (vs. traditional) outfit (no = 0; yes = 1). Second, we asked the participants whether they are “worried that the Himba culture is changing” (“Very worried” = 0, “Moderately, a little, or not worried” = 1; the latter three possible answers were combined into one score as they were chosen overall by just 15% of the sample) and whether they “like the life in Opuwo or other big cities” (“Not at all” = 0, “A little, moderately, or a lot” = 1; the latter three possible

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answers were combined into one score as they were chosen overall by just 23% of the sample). The scores to the four items were added to create an urbanicity index that could vary from 0 (low urbanicity) to 4 (high urbanicity). This index compounds urban-related behaviours (phone, outfit) and attitudes (worry about culture change, attitude towards the city). We do not disentangle these dimensions here, but additional descriptive analyses can be found in the Supplementary Material (<https://osf.io/m5vkt>) suggesting coherent relationships between each of the four items and Ebbinghaus susceptibility.

2.3 Ethics

The study was conducted following the Declaration of Helsinki and was approved by the ethics committee of Université Paris Cité (N°IRB 00012021-88). The French participants gave their written consent after being informed about the study purposes and procedures. The Himba participants, who were unable to read or write, provided oral consent in accordance with ethical guidelines (see full description of information and consent procedure for the Himba participants in Supplementary Material, at <https://osf.io/m5vkt>).

2.4 Data analysis description

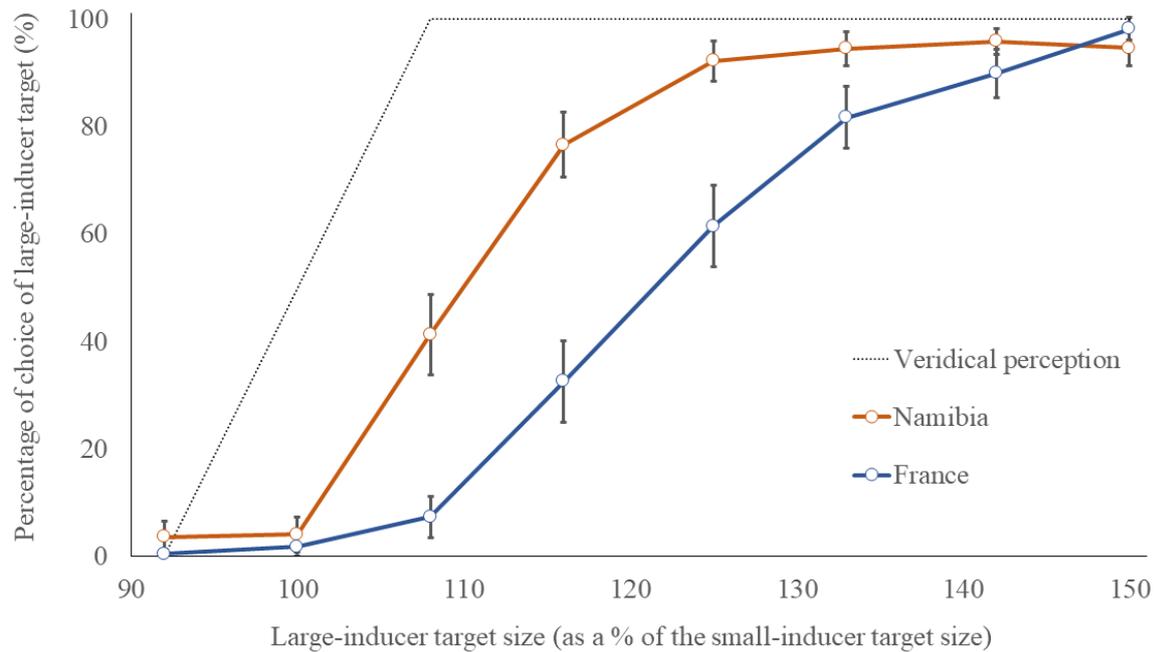
First, we contrasted the mean percentage of errors in the Ebbinghaus illusion task across Himba and French participants. Then, we performed analyses focusing on the Himba sample, to explore relationships between urbanicity, general cognitive ability, education, literacy, and susceptibility to the Ebbinghaus illusion. Analyses were performed using Jamovi (version 1.6.3.0; Jamovi, 2019; R Core Team, 2020; the full set of analyses can be found at <https://osf.io/m5vkt>).

3. Results

3.1 Susceptibility to the Ebbinghaus Illusion

Consistent with previous studies, French participants were more susceptible to the Ebbinghaus illusion (Mean errors on misleading trials 45.3%, SD = 21.7) than Himba participants (Mean errors on misleading trials 19.2%, SD = 16.1; see Figure 3), $t(215) = 10.1$, $p < .001$, $d = 1.36$.

Figure 3. Susceptibility to the Ebbinghaus illusion as a function of group (on the figure, a larger distance between a data point and the “veridical perception” line means a higher error rate)



Although the Himba sample was slightly slower on misleading trials (group median = 2011 ms) than the French sample (group median = 1810 ms), $t(214) = 2.29$, $p = .023$, $d = 0.311$, the difference was of a small magnitude (200 ms). In order to test whether such latency difference may drive the difference in illusion susceptibility across samples, we selected the fastest Himba participants using a median split (i.e., participants with mean RT < 2011 ms; $N=53$) and compared them to the slowest French participants (i.e., participants with mean RT > 1810 ms; $N=55$). While the subgroup of “fast” Himba participants was twice faster (subgroup median = 1452 ms) than the subgroup of “slow” French participants (subgroup median = 2792 ms), $t(106) = 10.2$, $p < .001$, $d = 1.97$, the fast Himba nevertheless perceived the illusion less strongly (Ebbinghaus errors, $M = 19.8\%$) than the slow French participants (Ebbinghaus errors, $M = 40.0\%$), $t(106) = 5.7$, $p < .001$, $d = 1.09$. Thus, unlike hypothesized by Bressan & Kramer (2021), the Himba vs French difference observed in this study did not seem to be driven by response latencies (an additional descriptive analysis of the relationship between latencies and illusion susceptibility can be found in Supplementary Materials).

3.2 Cognitive ability and urbanicity

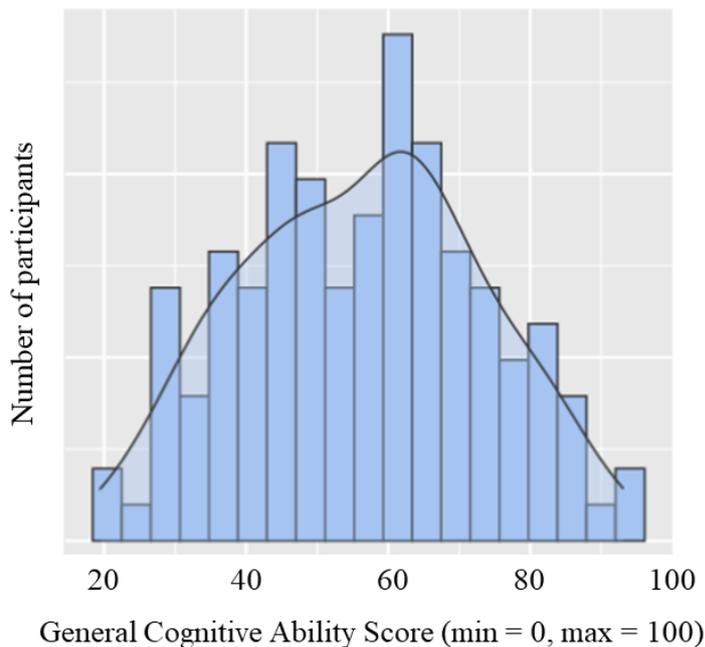
Accuracies at the digit-span, matrices and numeral ability tasks were all related (see Table 1), showing that they index a common underlying *g* factor. We computed a general-cognitive-ability score for each participant, by averaging accuracies at the three tasks. The cognitive-ability scores were normally distributed (Shapiro-Wilk test: $W = .988, p = .347$; see Figure 4).

Table 1. Relationships between cognitive ability tasks

	Digit Span	Numerical Ability
Numerical Ability	.404***	
Matrices	.457***	.371***

*** $p < .005$

Figure 4. Distribution of cognitive-ability scores in the Himba sample



Schooling and literacy were both related to cognitive ability; participants who received some formal schooling had a higher cognitive-ability score ($M = 64.6, SD = 15.9$) than those who did not ($M = 52.6, SD = 16.2$), $t(122) = 3.8, p < .001, d = 0.75$, and there was a positive

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correlation between cognitive-ability and literacy scores, $r(123) = .477, p < .001$ (Note that literacy scores were not normally distributed; descriptive statistics showed that 57% of participants had a score of “0.00”, 17% a score between “0.33” and “1.00”, 15% a score between “1.33” and “2.00”, and 11% a score between “2.33” and “3.00”).

Most importantly for the purposes of this study, urbanicity was also related to cognitive ability. While the relationship between number of visits to Opuwo and cognitive ability did not reach significance, $r(119) = .135, p = .144$, the relationship between urbanicity and cognitive ability did, $r(123) = .336, p < .001$. Note that Spearman’s correlations were used to analyse the significance of the relationships involving urbanicity (given that the latter was an ordinal variable that could vary from 0 to 4; 27% participants had a score of “0”; 40% had a score of “1”; 19% had a score of “2”; 16 participants had a score of “3”; and 2% had a score of “4”).

The relationship between urbanicity and cognitive ability might be partially explained by differences in formal schooling and literacy. Accordingly, schooled participants had a higher urbanicity score ($M = 1.76, SD = 1.15$) and went to Opuwo more often ($M = 4.80, SD = 3.75$) than unschooled participants (urbanicity: $M = 0.98, SD = 0.88$; Opuwo visits: $M = 2.58, SD = 2.69$), respectively, $t(125) = 4.1, p < .001, d = 0.79$, and $t(121) = 3.7, p < .001, d = 0.74$. In addition, urbanicity was positively related to literacy, $r(127) = .249, p < .001$.

The above findings confirm that, in this study, the index used to measure urbanicity was robustly related to (and thus potentially confounded with) the indices measuring education, literacy and, most importantly, general cognitive ability.

3.3 Predictors of susceptibility to the Ebbinghaus illusion in the Himba sample

Within the Himba sample, the only factor that predicted susceptibility to the Ebbinghaus illusion was urbanicity, $r(103) = .256, p = .008$. This result replicates previous

findings of a link between urbanicity and susceptibility to the illusion (Caparos et al., 2012; Bremner et al., 2016; Mavridis et al., 2020). Schooled participants were as susceptible to the illusion ($M = 21.0$, $SD = 15.8$) as unschooled ones ($M = 18.4$, $SD = 16.4$), $t(106) = 0.74$, $p = .462$, $d = 0.17$. Ebbinghaus errors did not correlate with any other variable (see Table 2).

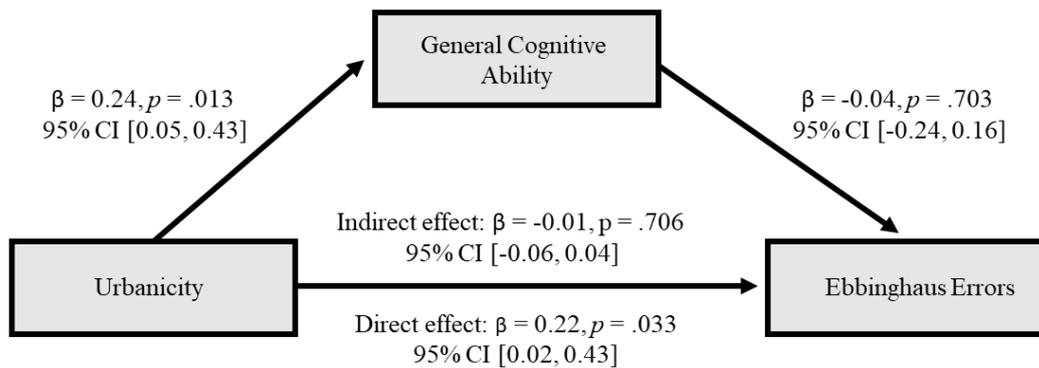
Table 2. Correlations between Ebbinghaus illusion errors and urbanicity, cognitive ability, education and literacy in the Himba sample

	Ebbinghaus errors	Urbanicity	Visits to Opuwo	General cog. ability	Numb. yrs at school
Urbanicity	.256*				
Visits to Opuwo	-.090	.386***			
General cog. ability	.016	.336***	.135		
Numb. yrs at school	.009	.362***	.345***	.360***	
Literacy	.038	.336***	.398***	.477***	.838***

* $p < .05$, ** $p < .01$, *** $p < .005$

In order to confirm that the relationship between urbanicity and susceptibility to the Ebbinghaus illusion was not driven by general cognitive ability, we ran a mediation analysis using urbanicity as predictor, general cognitive ability as mediator, and Ebbinghaus errors as dependent variable; while the direct path was significant ($\beta = 0.22$, $p = .033$; see Figure 5), the indirect one was not ($\beta = -0.01$, $p = .706$). The latter null effect (for the indirect path) was also observed when using either number of years of education ($\beta = -0.02$, $p = .586$) or literacy ($\beta = -0.01$, $p = .762$) as mediator.

Figure 5. Mediation model using urbanicity as predictor, general cognitive ability as mediator, and Ebbinghaus errors as dependent variable



In a final set of analyses, we explored the role of latencies (Bressan & Kramer, 2021). While there was a trend suggesting a negative relationship between urbanicity and latencies in the Himba sample, the latter trend was small and non-significant, $r = -.121, p = .219$, and there appeared to be no relationship between latencies and illusion size, $r = -.037, p = .706$. Thus, we found no evidence that the relationship between urbanicity and illusion susceptibility was driven by response latencies.

4. Discussion

Previous work has shown that non-Western observers living in non-industrialised societies are less susceptible to the Ebbinghaus illusion than Western observers. This cross-cultural difference has been ascribed to differences in urbanicity (Bremner et al., 2016; Caparos et al., 2012; Köster et al., 2018; Mavridis et al., 2020), where urban environments would foster greater sensitivity to contextual information (Linnell et al., 2013; Miyamoto et al., 2006) and/or to geometrical shapes (Segall et al., 1966). The present study explored whether general cognitive ability may instead act as a confounding variable and mediate the relationship between urbanicity and susceptibility to the Ebbinghaus illusion.

First, the study replicated previous findings and showed that Western participants – French individuals from greater Paris – were massively more susceptible to the Ebbinghaus illusion than non-Western participants – Himba individuals from Northern Namibia. In addition, within the Himba sample, susceptibility to the Ebbinghaus illusion was positively related to urbanicity, confirming a number of previous findings (Bremner et al., 2016; Caparos et al., 2012; Köster et al., 2018; Mavridis et al., 2020).

In this study, urbanicity was measured using an index of ‘urban tropism’, which was computed using a mix of observational variables (possession of a phone, wearing of traditional vs modern/urban outfit) and attitudinal variables (reported attitude towards the city and towards preserving traditional values against urban ones). This variable correlated to actual behaviours: participants with a stronger level of urbanicity went to town more often. The links between urbanicity and perception that we report here may be accounted for by actual effects of urban exposure (external effects), for instance through an impact of urbanicity on attention to contextual information (Linnell et al., 2013; Miyamoto et al., 2006). Alternatively, they might be explained by underlying attitudes towards urban environments (internal effects). Such attitudes may be related to personality traits, such as agreeableness, themselves shown to be linked to illusion susceptibility (Makowski et al., 2023).

The present work cannot distinguish between these external and internal accounts. Future studies in non-Western samples may measure whether the attitudes of urban dwellers towards urban environments (i.e., individuals who live in town permanently) predict the susceptibility to the illusion, which may argue for an impact of attitudes more than actual exposure. Given that the impact of urban environments is doubtlessly multifactorial, substantial work remains necessary to explain its underpinnings.

The present study showed robust relationships between urbanicity, on the one hand, and education, literacy, and general cognitive ability, on the other. The latter variable was

computed by collapsing the performance at three tasks (numerical ability, forward-digit span, and a short version of the WAIS matrices). Despite the robust relationships between urbanicity and these variables, none of them predicted susceptibility to the illusion. In other words, the link between urbanicity and Ebbinghaus susceptibility was not mediated by education, literacy, or general cognitive ability. These results are somewhat reassuring with regard to the findings of previous studies that did not control for individual differences in general cognitive ability. Nevertheless, the strong relationship between the latter variable and urbanicity advocates for careful considerations in future studies, and attempts to control for potential confounding effects of education, literacy and/or general cognitive ability.

One novelty of this study was to show that it is possible, using a simple and straightforward setup, to measure individual differences in general cognitive ability, in a sample of remote, unschooled participants. The three tasks that we chose were selected on the basis of their feasibility by non-literate populations. The forward-digit span task has previously been used in numerous non-WEIRD populations (Linnell et al., 2013; Blanchette et al., 2018). The results at the numerical ability task showed that even unschooled participants can perform simple calculations. This finding is unsurprising in populations of herders, who must master some basic mathematical competency, for instance to manage their stock. Finally, the WAIS matrices is an intuitive and easy-to-understand task. The reliable relationships between the scores at these three tasks, and the fact that they strongly correlate with education and literacy, suggests that they do index a shared underlying *g* factor.

In summary, the present study replicated previously observed cross-cultural differences in susceptibility to the Ebbinghaus illusion, between Western and non-Western samples, and it showed that urbanicity was related to susceptibility to the illusion in the non-Western sample. It did not speak as to the underlying driver of the latter relationship, which may be explained by exposure to carpentered and cluttered visual environments (Segall et al.,

1966; Miyamoto et al., 2006), by the impact of cognitive load on attention (Linnell et al., 2013), or by internal drivers such as personality traits (Makowski et al., 2023). Most importantly, although the results showed that general cognitive ability, literacy or education did not mediate the effect of urbanicity, they also showed that the latter variable is strongly confounded with the former three, and that it is important to control for individual differences in these variables in future studies about the cognitive impact of urban environments.

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Authors contribution

XX: Conceptualization; Methodology; Investigation; Data curation; Formal analysis; Funding acquisition; Project administration; Visualization; Writing original draft.

XX: Conceptualization; Investigation; Formal analysis; Writing review & editing.

Compliance with Ethical Standards

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and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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