The Immediate Positive "Size" of Negative Emotions: Are Older Adults Less Prone to Visual Illusions?

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Abstract

Individuals organize visual sensations into meaningful information according to physiological mechanisms as well as experience, motivation and expectations when interacting with the environment. However, few studies have focused on age differences and the influence of affective information on visual perception. Accordingly, 200 younger and 200 older adults, in two experiments, viewed a classical and an affective version of the Ebbinghaus illusion. In the affective version, participants saw a happy, angry, or neutral black and white face (Experiment 1 and 2). Subsequently, participants were asked to remember the size of the target circle (Experiment 2). Older adults were less subject to the Ebbinghaus illusion compared to younger adults when comparing negative configurations. In addition, older adults made more errors with the size of the positive configurations on the later size judgment test. Results highlight a role of affective valence in perceptual illusions and the interaction between aging and emotion during online and offline use of perceived size information.

Keywords: Visual illusions; Aging; Emotion

Introduction

To make sense of the surrounding environment and effectively interact with it, individuals must organize incoming visual sensations into meaningful information. Yet, the perceptual organization and interpretation of visual input is often a difficult task, influenced by experience, expectations and motivation and therefore, subject to error. Cognitive visual illusions, in fact, are fascinating "tricks" of perception created when people visually perceive environmental stimuli according to their perceptual expectations in a way that differs from objective reality.

Cognitive illusions can be defined as the knowledge and assumptions or unconscious inferences an individual has about the world and can then be divided into three main categories: ambiguous illusions, distorting illusions, and paradox, or fiction, illusions. One of the most classical examples of this last type of visual illusion is the so-called Ebbinghaus Illusion or Titchener circles [1]. This illusion occurs when two circles of identical size are presented side by side with one surrounded by large circles while the other is surrounded by small circles. Typically, the target circle surrounded by small circles is perceived as being larger than the same configuration surrounded by large circles when, in fact,

both inner circles are the same size. Interestingly, these types of distortions are widely documented in many different laboratory situations and are an extensive area of research in perception yet, when it comes to the explanations behind them, no single explanation is sufficient. Indeed, various studies have shown that a number of processes, from early optical to late perceptual processes, appear to be involved.

In one study, researchers [2] reviewed a series of theoretical explanations based on an automatic perceptual mechanism. According to these explanations, individuals compare the target circle and the surrounding circles using a perceptually-based contour interaction mechanism that leads them to misjudge the size of the target circle. In fact, contour theories explain the illusion in terms of interactions between the visual representations of the physical contours of the stimulus. Accordingly, the size misjudgment that this illusion causes is due to the neural displacement of visual contours.

Moreover, since aspects of size perception predominantly depend on the ventral pathway, studies have also shown a long developmental time-course. In fact, many developmental studies

have shown how the magnitude of this illusion changes as children grow [3]. Interestingly, fewer studies have investigated whether there are adult age-related differences in the Ebbinghaus illusion. Some researchers [4] studied the effect of aging on shape distortion (that is, the shape of a second stimulus immediately following the first one appears distorted) and found that this visual illusion decreased with advancing age. Some researchers [5] found that motion illusory effects decreased with age. Some researchers [6] showed that the magnitude of Muller-Lyer illusion decreased when younger adults' visual acuity was reduced to simulate age effects and seems to suggest a general reduction of visual illusions as people age.

Two different mechanisms underlie age changes in illusions. On one hand, illusions may be linked to physiological factors such as pupil size, increased lenticular density, and retinal pigmentation. That is, physiological changes in the visual system affect the magnitude of illusions. Consequently, older adults who are typically more subject to these changes may show decreases in the magnitude of visual illusions. On the other hand, illusions can be directly related to previous experience and semantic processing, both functional in older adults. In this case, the magnitude of visual illusions may remain stable, or even increase, as individuals age.

Context theories, instead, are not grounded in neural mechanisms. These theories underline the importance of environmental cues in influencing a psychological process so that individuals make sense of their surrounding environment and effectively interact with it. Indeed, sensibility to context is a hallmark of cognitive systems [7] and in everyday situations individuals often depend on contextual factors such as perceptual, conceptual and emotional cues to disambiguate local signals that, considered independently of the broader context, can be open to alternative interpretations. Accordingly, studies about the effects of context on size perception have contributed to a wide range of issues including debates concerning the conditions under which the effects occur and how they are interpreted.

Recent explanations include greater contributions of memory processes in the generation of visual illusions [8] and assume that the activation of memorial contents may influence the perception of that content. This account generally predicts larger sensibility to visual illusions or stable illusory effects in aging since older adults show preserved semantic memory components and typically have more previous experiences compared to younger ones. In addition, sensibility to visual illusions may also depend on different memory components. For example, De Fockert [9] showed that high working memory load leads to more illusions. If this is the case, older adults should again be more subject to perceptual illusions since they typically show reduced working memory capacity.

In summary, the above-mentioned studies suggest that both lower and higher level visual processes contribute to create visual illusions. If so, older adults' performance may help disentangle and better clarify the role of bottom-up and top-down processes in generating perceptual illusions. Consequently, our first aim was to investigate age differences in the Ebbinghaus illusion by presenting a group of younger and older adults a classical version of the illusion. In this manner, any differences found between younger and older adults should be principally caused by bottom up processes linked to physiological changes in the visual system.

The second focus of our study was on the interaction of between emotional factors and perceptual illusions in aging. Emotions give sense to the surrounding environment and make life meaningful. Moreover, emotions directed towards objects, events, or situations, can be powerful sources of motivation that may subsequently lead older adults to invest more in motivated behaviors and consequently change the way they interpret perceptual input and the behaviours they adopt [10,11].

In line with this, recent research has begun to explore how emotions may also alter perception in general, and visual illusions in particular, rendering the study and explanations of perceptual illusions even more complex and intriguing [12]. Some researchers [13], for instance, found that emotions enhanced sensibility to contrast and explained this benefit as due to the influence of amygdala on visual processing regions. Another study by Van Ulzen, Semin, Oudejanas, and Beek [14], after having eliminated three participants found that emotional content may affect the Ebbinghaus illusion in a group of younger adults in certain conditions. In their study, they constructed configurations using positive, negative and neutral pictures portrayed as circles and asked participants to adjust the size of the comparison circle to match the perceived size of the target one. Results showed how the size of negative loaded circles were underestimated less than the positive and neutral circles. In other words, negative circles were less subject to distortions than positive and neutral ones and consequently led to a reduction in the Ebbinghaus illusion.

Another study [15] explained these effects of emotion on visual illusions by distinguishing between global and local perception. When individuals are happy or focused on positive information, they often adopt a more global perceptual style and tend to show a preference for the perception of wholes. Differently, when participants are sad or focus on negative content, they tend to adopt a local style and mainly focus on details. Given that attention to details leads to a decrease in illusion as shown by Ulzen et al. [14], we may expect a reduction of the illusion in aging when focused on negative content. If so, in line with previous studies [16], we expect older adults to show larger illusory effects with positively-charged and/or neutral stimuli compared to negative ones since global processing facilitates the occurrence of this illusion.

A complementary hypothesis is that older adults attend more to their overall environment [17]. Consequently, when paying attention to negative content and subsequently constrained to a detailed analysis, they may show an even greater reduction in illusions compared to younger adults.

Another important aspect regarding the interaction between emotion, perception and aging is the temporal dynamics of valence. Indeed, negative information generally operates in immediate temporal windows just as visual illusions and negative information quickly captures attention because it is based on

more automatic attentional processes. Differently, positive emotions seem to emerge later and require a greater amount of cognitive control. In particular, numerous eye tracking and ERP studies reviewed by Mather [18] showed how older adults' suppression of negative information immediately impacts basic visual perception, while positivity effects emerge later [19]. In line with this, older adults who withdraw their attention from negative information may show reduced visual processing for this type of information. In this case, we expect older adults to show a decrease in the Ebbinghaus illusion only for negatively-charged stimuli during online visual processing linked to their tendency to avoid looking at negative information.

Moreover, this attention withdrawal may be particularly true for attention and memory processes when stimuli are presented in sequence (one after the other) and for a limited amount of time [20,21]. Instead, when older adults are forced to process negative information online by asking them to scan and compare two negative perceptual configurations, it is impossible for them to withdraw attention from negative information. In this case, older adults may show typical effects linked to the influence of negative content on perception such as a greater focus on detailed information that can be even magnified by their tendency to avoid negative information. If so, we expect a greater reduction in the illusion compared to younger adults. Instead younger adults who are typically less sensitive to emotion processing, should show a comparable pattern of errors across different emotional stimuli. A series of studies [19], in fact, showed that younger adults tended to show either no or only a slight preference for emotional information.

Last, since illusions operate in an extremely limited time interval, a strong focus on positive valence during online processing may not be possible. For this reason, and in order to better study the role of subsequent memory processes, we asked participants to recall target size and indicate the size of the target circle among a series of different sized circles.

If older adults show a general focus on information of any type but negative, this preference would later increase their sensitivity to the illusion and lead to a an increase in size judgment errors. In particular, if older adults' perception is biased towards positive information, we expect older adults to make more errors after viewing positively valenced configurations than younger adults showing how experience and semantic processing influence the interpretation of visual input in order to make sense of and interact with the environment.

Experiment 1

Participants: One hundred and eleven older adults between 60 and 87 years of age were recruited from the local community in the Chieti area. Eleven participants were excluded because they scored below 25 on the Mini-Mental State Examination [22] leaving one hundred older adults. We also recruited 100 younger adults between 18 and 25 years of age from a pool of volunteer undergraduate students at the University of Chieti. We conducted the study in accord with the Code of Ethics of the World Medical Association (Declaration of Helsinki) and informed consent was

obtained from all participants. All participants were community dwelling and free of major neurological and psychiatric problems with normal or corrected to normal vision. The total number of participants is appropriate as per a priori power analysis. Power analysis suggests that there is a 0.95 probability for detection of small effect using 98 participants. The estimation of small effects is derived from prior studies [16].

Before beginning the experimental task, we screened all participants for their general cognitive and affective abilities. Participants' characteristics and statistical t-test comparisons are presented in Table 1. In particular, participants did not differ in years of education. With respect to neuropsychological tests, older adults significantly differed from younger adults on measures of working memory, the Digit Span test from the WAIS–R [23]. There were no differences between younger and older adults on the Positive and Negative Affective Scale, PANAS (**Table 1**) [24].

Materials

We created 12 Ebbinghaus Illusion trials. Six trials adopted a classical configuration with yellow target circles surrounded by 5 large or small blue circles. Three of the classical versions created the illusion to the right while the other three showed the illusion to the left. We also created 6 examples using a black and white valenced faces selected from the Karolinska Directed-Emotional Faces Database. The central target figure in both the classical and valenced facial version measured 2 cm, the larger surrounding circle measured 3-5 cm. The smaller faces/circles were 1 cm. In this manner, stimuli were ± 1, 5 cm with respect to the target.

Older participants saw an older face and younger participants saw a younger face to reduce own-age biases [25]. The face was portrayed as circle. Two of the trials used a positive version of the face (happy expression), two used a negative version (angry expression) and two a neutral version (neutral expression). Target and surrounding circles were always congruent in valence. (**Figure 1**) for an example of a valenced trial and one version of each valenced face. Again, trials were balanced for left and right versions of the illusion. Finally, as in the classical non-valenced version, the centre target face was about 1.7 cm in diameter while the larger outer faces were about 3.5 cm in diameter and the smaller faces 0.8 cm.

Procedure

After collecting demographic information and evaluating general cognitive abilities, participants were seated approximately 40 cm from the computer screen and informed that they would view a series of slides. Each trial started with a 1s. fixation cross in the center of screen immediately followed by a slide with the two illusory configurations. We presented the slides with Microsoft PowerPoint in a fixed order with the restriction that no two consecutive examples were identical. Each slide presented a version of the illusion with the capital letters A o B underneath. Participants were instructed to select the target circle they perceived as largest between the two configurations as quickly as possible. Participants saw a total of 16 trials; 12 valenced

Table 1: Participant characteristics by age group for experiment 1 and 2.

	Experiment 1		Experiment 2		
	Younger (n=100)	Older (n=100)	Younger (n=100)	Older (n=100)	
Characteristic	M (SD)	M (SD)	M (SD)	M (SD)	
Age (in years) ***67.8 (6.9)	20.6 (1.5)	***67.8 (6.9)	20.7 (1.6)	***	67.3 (7.2)
Sex	44M, 56F	53M, 47F	40M, 60F	52M, 48F	
Education (in Years)	14.6 (0.6)	14.0 (3.4)	13.9 (0.9)	13.3 (3.6)	
MMSE		27.5 (2.6)		27.2 (2.8)	
DigitSpan Forward	6.7(1.2)	6.9 (9.5)	6.9 (1.3)	7.1 (2.3)	
DigitSpan Backward 6.0	(1.3) ***	4.6 (2.7)	6.2 (1.4) ***	5.2 (2.2)	
PANAS Positive	31.3 (5.4)	33.1(8.5)	31.4 (6.0)	29.7 (9.3)	
PANAS Negative	1.9 (4.1)	20.1 (8.1)	22.5 (5.5)	21.1 (5.1)	
Note. MMSE=Mini-Mental State Examination [23].					
*p<0.05; **p<0.01; ***p<0.001.					

versions (4 positive, 4 negative and 4 neutral). For each valence, two illusions were to the right and two to the left. Participants also saw 4 classical versions of the illusion, again 2 to the right and two to the left. Each participant saw two versions for each valence (positive, negative and neutral) for a total of 6 facial versions counterbalanced for position of illusion (right and left). The experimenter recorded the participant's verbal responses using an excel sheet. Before starting the experimental session, each participant saw a practice trial that used colored circles not used in the experimental session. All participants were debriefed at the end of the session. The experimental session lasted about 10 min.

Ethics Statement

The study was approved by the Departmental Ethics Committee at the University of Chieti. In accordance with the Declaration of Helsinki, all participants gave written informed consent prior to inclusion in the study.

Results and Discussion

We analyzed experimental data with STATISTICA 7. First, we performed a mixed design Analysis of Variance (ANOVA) to investigate effects associated with illusion type (control *vs.* face) and age differences. Second, we performed a mixed design ANOVA to study valence (positive, negative and neutral) effects and age differences. Independent samples t-tests were employed post hoc to identify any differences between groups.

On-line accuracy scores calculated as the percentage of times the illusion occurred for each age group and stimulus type are reported in (**Table 2**).

A 2 (age: younger *vs.* older adults) × 2 (stimulus type: classical *vs.* face) analysis of variance (ANOVA) on accuracy scores showed a main effect of age, F (1.198)=45.65, p<0.001, ηp2=0.187 since younger adults were more subject to the illusion than older adults. There was a main effect of stimulus type F (1.198)=62.66, p<0.001, ηp2=0.24 because the classical version of the illusion was stronger than the affective version. Finally, the two way age stimulus type interaction was significant, F (1.198)=41.32, p<0.001, ηp2=0.173 since older adults were less subject to the

illusion with faces than coloured circles (LSD post hoc, p<0.001).

On-line accuracy scores calculated as the percentage of times the illusion occurred for each age group and valence are reported in (**Table 3**).

To further clarify on-line emotional effects we conducted a second 2 (age: younger *vs.* older adults) × 3 (valence: positive, negative and neutral) analysis of variance (ANOVA) on accuracy scores in the valenced trials alone. We found a main effect of age, F (1.198)=78.99, p<0.001, ηp2=0.285 since younger adults were again more subject to the illusion than older adults. There was a main effect of valence, F (2.396)=37.59, p<0.001, ηp2=0.159. Analyses post hoc confirmed that the illusion occurred more when faces were neutral with respect to valenced faces and more with positive faces than negative. Finally, the two-way age × valence interaction was significant F (2.396)=51.08, p<0.001, ηp2=0.205. An analysis post hoc confirmed that older adults were less subject to illusions when faces were negative.

Experiment 2

Participants: One hundred and fifteen older adults between 60 and 87 years of age were recruited from the local community in the Chieti area. Fifteen participants were excluded because they scored below 25 on the Mini-Mental State Examination [22] leaving one hundred older adults. We also recruited 100 younger adults between 18 and 25 years of age from a pool of volunteer undergraduate students at the University of Chieti. None of the participants had participated in Experiment 1. Again, the total number of participants is appropriate as per a priori power analysis. Power analysis suggests that there is a 0.95 probability for detection of small effect using 98 participants. The estimation of small effects is derived from prior studies [16].

We conducted the study in accord with the Code of Ethics of the World Medical Association (Declaration of Helsinki) and informed consent was obtained from all participants. All participants were community dwelling and free of major neurological and psychiatric problems with normal or corrected to normal vision. Before beginning the experimental task, we screened all participants for their general cognitive and affective abilities.

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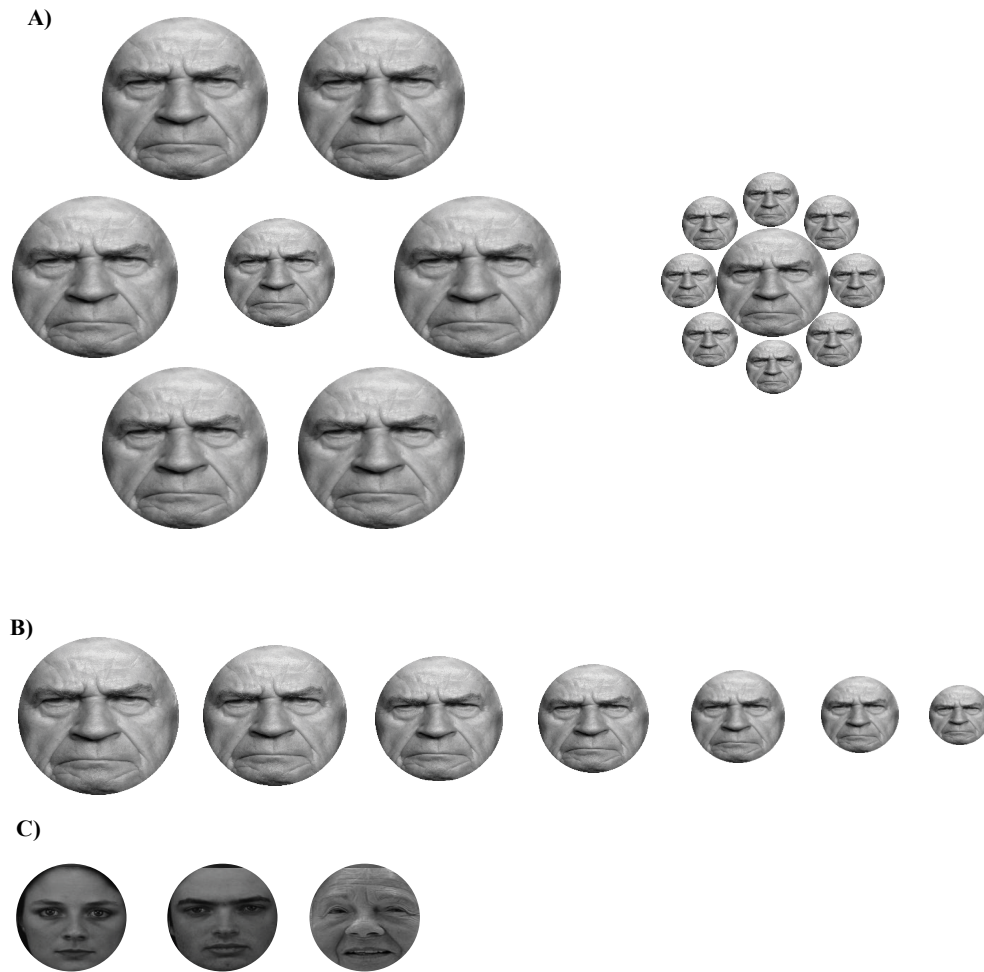
Figure 1 Example of valenced stimuli used during online (A) and offline (B) processing (C) older female, younger male and female.

Table 2: On-line accuracy by age group and type of stimuli for experiment 1 and 2.

Generation	Experiment 1		Experiment 2	
	Classic	Face	Classic	Face
Younger (n=100)	99.0 (.10)	98.0 (1.0)	99.0 (1.8)	97.8 (1.4)
Older (n=100)	96.2 (.10)	85.0 (1.0)	89.3 (1.8)	75.0 (1.4)

Table 3: On-line accuracy by age group and valence for experiment 1 and 2.

	Experiment 1			Experiment 2		
	(Face) Pos	(Face) Neg	(Face) Neu	(Face) Pos	(Face) Neg	(Face) Neu
Younger (n=100)	99.5 (1.9)	99.5 (1.8)	99.0 (1.1)	95.0 (2.4)	99.5 (0.9)	99.0 (2.0)
Older (n=100)	91.5 (1.9)	68.0 (1.8)	95.5 (1.2)	87.0 (2.4)	50.0 (0.9)	88.0 (2.0)

Participants' characteristics and statistical t-test comparisons are presented in Table 1. In particular, participants did not differ in years of education. With respect to neuropsychological tests, older adults significantly differed from younger adults on measures of working memory, the Digit Span test from the WAIS–R, [23]. There were no differences between younger and older adults on the Positive and Negative Affective Scale, PANAS, [24].

Material and Procedure

Illusion stimuli were the same as in Experiment 1. In this study, we also created an additional 12 test slides for a later memory test. Test slides contained 7 versions of the center target illusion stimulus (yellow circle or valenced face) that ranged in size from 1.3 cm to 2.8 cm. Slides were balanced smallest to largest or

largest to smallest according to the direction of the preceding illusion. In the scaled versions, we constructed 7 stimuli starting from the original target size (2 cm) and then created 6 other versions by ± 0-3 cm.

We presented all stimuli with Microsoft PowerPoint in a fixed order with the restriction that no two consecutive examples were identical.

After each experimental illusory trial, a slide with the number 10 in the center appeared and participants were instructed to begin counting backward. The slide remained on the screen and participants counted backward for 5 seconds. Finally, the test slide appeared and we asked participants to choose the image that they felt was the same size chosen on the illusion slide. The experimenter recorded the participant's verbal responses using an excel sheet.

Before starting the experimental session, each participant saw a practice trial that used colored circles not used in the experimental session. The experimental session lasted about 15 min. All participants were debriefed at the end of the session.

Results and Discussion

On-line effects: On-line accuracy scores calculated as the percentage of illusions for group and stimulus type are reported in **Table 2**.

A 2 (age) × 2 (stimulus type) analysis of variance (ANOVA) on accuracy scores showed a main effect of age, $F_{(1.198)}=56.56$, $p<0.001$, $\eta p2=0.222$ since younger adults were more subject to the illusion than older adults. There was a main effect of stimulus type $F_{(1.198)}=122.48$, $p<0.001$, $\eta p2=0.382$ as the classical version of the illusion was stronger than the affective version. Finally, the two way age × stimulus type interaction was significant, $F_{(1.198)}=88,21$, $p<0.001$, $\eta p2=0.308$ since older adults were less subject to the illusion when we used faces with respect to colored circles (LSD post hoc, $p<0.001$).

On-line accuracy scores calculated as the percentage of illusions for age group and valence are reported in Table 3.

To examine on-line emotional effects, we conducted a 2 (age) × 3 (valence) analysis of variance (ANOVA) on accuracy scores in the valenced trials alone. We found a main effect of age, $F_{(1.198)}=138.35$, $p<0.001$, $\eta p2=0.411$ since younger adults were again more subject to the illusion than older adults. There was a main effect of valence, $F_{(2.396)}=84.93$, $p<0.001$, $\eta p2=0.300$. An analysis post hoc confirmed that the illusion occurred more when faces were neutral with respect to valenced faces and more with positive faces than negative. Finally, the two-way age × valence interaction was significant $F_{(2.396)}=109.72$, $p<0.001$, $\eta p2=0.357$. An analysis post hoc confirmed that older adults were less subject to illusions when faces were negative.

Off-line effects: Off-line accuracy scores, calculated as the number of times participants correctly chose the circle that was the same size as the center circle in the illusion slide, for age group and stimulus type are reported in (**Table 4**).

An ANOVA with accuracy scores, as dependent variables and age and stimulus type as independent variables did not show a main effect of age, $F_{(1.198)}=1.75$, $p=0.19$, $\eta p2=0.009$ as older adults were as accurate as younger adults in choosing the image of the correct size. There was no main effect of stimulus type, $F_{(1.198)}=0.049$, $p=0.82$, $\eta p2=0.0002$. However, the two way age × stimulus type interaction was significant, $F_{(1,198)}=5.53$, $p<0.05$, $\eta p2=0.027$ since younger adults choose the correct size of the circle in the classical version better than older adults, while older adults did as well as younger adults when choosing the size of the face.

Off-line accuracy scores calculated as percentage of times participants correctly chose a circle that was the same size as the chosen center target circle used in the illusion slide for age group and valence are reported in (**Table 5**). To examine off-line emotional effects we carried out a second Analysis of Variance (ANOVA). There was no main effect of age $F_{(1.198)}=0.077$, $p=0.78$, $\eta p2=0.0003$. The main effect of valence was significant $F_{(2.396)}=3.21$, $p<0.05$, $\eta p2=0.016$. An analysis post-hoc confirmed that participants did better on neutral trials than emotional trials. There were no differences between positive and negative trials. Finally, the two way age x valence interaction was significant $F_{(2.396)}=3.15$, $p<0.05$, $\eta p2=0.016$. A post-hoc analysis confirmed that valence did not affect younger adults' performance, while older adults did worst with positive stimuli than neutral stimuli while there was no difference between neutral and negative stimuli.

Table 4: Off-line accuracy (mean and SE) by age group and type of stimuli for experiment 2.

Generation	Classic	Face
Younger (n=100)	47.8 (3.0)	41.5 (3.0)
Older (n=100)	37.5 (3.0)	42.7 (3.0)
Note. Accuracy = Percentage correct size response.		

Table 5: Off-line accuracy (mean and SE) by age group and valence for experiment 2.

	Face		
	Pos	Neg	Neu
Younger (n=100)	42.5 (3.7)	38.5 (3.8)	43.5 (3.8)
Older (n=100)	35.5 (3.7)	44.0 (3.8)	48.5 (3.8)
Note. Accuracy = percentage correct size response.			

General Discussion

Our results support the idea that older and younger adults are, generally, equally affected by the illusion (classical version) and suggest that aging does not affect the magnitude of the classical version of the Ebbinghaus illusion when additional environmental features are missing. Indeed, we did not find differences between the two groups when we used colored circles as stimuli and both groups of participants showed comparable illusory effects with the illusion occurring almost 100% of the time. This may be because older adults tend to focus on the overall contours making their perceptual processing become more globally-based [15]. Given that this type of illusion is generated by the interaction between the target circle and the surrounding contextual information, older adults were as sensitive to this illusion as younger adults.

Differently, the pattern of performance changed when we added affective information. Specifically, older adults were less subject to illusory effects when faces included affective information. This may be due to general greater attentional deployment for face processing which may have reduced the overall effect. In addition, older adults are worse at identifying facial expressions compared with younger adults [26,25] which may explain a tendency to do the task with a more-local analysis and scanning of the configurations if compared with the classical version. This may ultimately hamper the generation of the illusion.

We also found that valence modulated online illusory effects for the negative configurations only in older adults. That is, greater attentional focus on local details may protect older participants from being deceived by two negative configurations. Recent literature on emotion processing and aging pointed to the well-established finding that older adults tend to withdraw their attention from negative information [21,27-29] and consequently may show reduced visual processing for this type of information [30]. Accordingly, a reduction of the Ebbinghaus illusion may be expected with negatively-charged stimuli. However, we believe that this account does not entirely explain our results as stimuli were not presented in sequence as usually happens in attention and memory studies. Here, older adults were forced to process negative information online and therefore less subject to attention withdrawal from negative stimuli, while in our study, it is more likely that older adults showed typical effects linked to the influence of negative content on perception. That is, older adults showed a greater focus on detailed information when faced with simultaneous presentation of negative stimuli and this may even be magnified by their tendency to avoid negative information [3]. Such an explanation seems to be supported when we compared online and offline perceptual processing as well. In fact, a clear-cut difference in the way emotion affects visual illusion in aging occurred in terms of online and offline processing. Online processing of negative material especially protected older adults from illusory effects while positive valence led to an increase in errors in a later judgment size task. That is, older adults' general bias towards positive information particularly damaged their later memory performance as they made more errors when asked to remember the size of the target circle they had chosen. This may be because positive content has been shown to lead participants towards global processing and to pay attention to the entire picture [14]. Consequently, when asked to remember the exact size of the target item, older adults were less able to identify it.

To conclude, our study is not without limitations. Most importantly, future studies on emotion processing and how emotion processing affects cognition need to consider gender differences. Here we chose to exclude this variable but a recent6] that systematically examined emotional processing as a function of age reported gender as a key variable. Here, we did construct stimuli to avoid gender specific effects linked to the stimuli (i.e., older adults remember pictures of older adults better than pictures of younger adults and younger adults remember pictures of younger adults better than pictures of older adults), but we did not examine gender differences in emotion processing. Nonetheless, the same pattern of results for online data suggests that negative valence was efficient in reducing illusory effects in aging. Therefore, the first main finding from this study is that when forced to process negative information, older adults cognitive processing become less focused on global aspects and more locally biased. A second relevant finding is that the effect of positive valence may not occur in immediate perceptual processes, but may emerge later, especially in terms of memory processes, and lead to more offline illusory effects [31,32].

Altogether, these data offer new insights on how emotions may interact with aging in modulating environmental visual illusions and invite researchers to manipulate valence in different perceptual illusions. It is possible that depending on the contribution of top-down and bottom-up processing, positive and negative valence may differentially affect the generation of visual illusions in aging.

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