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The Effect of Aging on the Dual-Route Model of Emotion Processing Applied to Memory Recognition

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Objective: Emotional faces are automatically processed in the human brain through a cortical route (conscious processing based on high spatial frequencies, HSF) and a subcortical route (subliminal processing based on low spatial frequencies, LSF). How each route contributes to emotional face recognition is still debated, and little is known about this process in aging. ***Method:*** Here, 147 younger adults (YA) and 137 older adults (OA) were passively presented with neutral, happy, and angry faces, shown as (a) unfiltered, (b) filtered at LSF, and (c) hybrid (emotional LSF superimposed to the neutral HSF of the same face). In a succeeding recognition phase, the same faces and new faces were shown as unfiltered, and participants were asked whether each face had been already presented in the encoding phase. ***Results:*** Despite the better performance by YA compared with OA for neutral faces presented as unfiltered (cortical route), the performance of OA was better than that of YA for angry faces presented as hybrid and for happy faces presented at LSF and as hybrid. ***Conclusions:*** We conclude that the activity of the subcortical route during the encoding phase facilitates emotional recognition in aging. Results are discussed in accordance with the dual-route model.

Key Points

Question: Emotions are particularly important for our daily life, so much so that in the evolution of humans two cerebral routes have developed to simultaneously process emotional valence, one at a subliminal level and the other one at a conscious level. ***Findings:*** Younger compared with older participants revealed a better memory performance when a conscious emotional face processing was required. Nevertheless, emotional faces were better recognized by older compared with younger participants when presented filtered at low spatial frequencies, implying a higher functioning of the subliminal emotion route in aging. ***Importance:*** Subliminal processing might be strengthened in older adults, with the aim to compensate for the expected and physiological memory decline. ***Next Steps:*** Further study should be carried out to investigate whether this result is specific for face processing or can be generalized to other stimuli.

Keywords: emotion processing, spatial frequencies, hybrid faces, aging

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The data that support the findings of this study are available from the corresponding author upon reasonable request. The experiment was not preregistered. Informed consent was obtained from all individual participants included in the study.

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According to the dual-route model proposed by LeDoux (1996) for emotional stimuli, two distinct cerebral routes are involved in emotion detection: the cortical route, responsible for a detailed and conscious processing of visual stimuli, and the subcortical route, responsible for a fast but unconscious analysis of visual inputs (Johnson, 2005; Morris et al., 1999). The simultaneous activity of both routes ensures fine processing of the details of the stimulus through the activity of the parvocellular pathway (cortical route), involving temporal and prefrontal cortical areas and mainly based on the high spatial frequencies (HSF) of the image, together with a rough processing of the stimulus based on the activity of the magnocellular pathway (subcortical route), involving limbic structures and mainly devoted to the analysis of the low spatial frequencies (LSF) of the image (Boucart et al., 2008; Vuilleumier et al., 2003; Williams et al., 2004).

To experimentally test this model, a category of images was created to elicit the activity of each route in the processing of different information conveyed simultaneously but at different spatial frequencies, namely, hybrid stimuli (Schyns & Oliva, 1994). In emotional hybrid faces, the emotional information is present in the LSF of the image and is subliminally processed by the subcortical route, being "hidden" by the HSF of the image conveying neutral information processed by the cortical route. Indeed, the cortical-conscious processing of the HSF of the image prevents observers to explicitly elaborate the emotional content contained in its LSF, which would be anyway processed through the subcortical route, but only at a subliminal level. In their pioneering study with hybrid stimuli, Laeng et al. (2010) found that participants were unable to explicitly (consciously) categorize the emotional expression of hybrid stimuli, but they judged hybrid faces containing a happy expression filtered at LSF as more friendly than hybrid faces containing an angry expression in the LSF range (in both cases HSF were neutral in valence). This suggested that the explicit categorization of facial expression may be mainly based on the activity of a cortical route leading to a conscious detection of only the information shown at HSF (i.e., neutral expression; as also discussed by Prete, Capotosto, et al., 2015, 2018; Prete et al., 2019; Wyczesany et al., 2018). Nevertheless, the friendliness scores were modulated by the LSF emotional information, as confirmed in a number of following studies (Prete, D'Ascenzo, et al., 2015; Prete, Laeng, et al., 2015, 2018; Prete et al., 2014; Tommasi et al., 2021), suggesting that the emotional information shown in the LSF is sufficient to modulate the implicit processing of the stimuli, through the activity of the subcortical route—a speculation further confirmed by the evidence that a patient with an amygdala lesion did not show such an implicit modulation of the friendliness judgment for hybrid stimuli (Laeng et al., 2010).

However, few and contrasting results have been described concerning the effect of aging on the activity of the dual route. At a perceptual level, an age-related decline in the processing of HSF was found (Barber et al., 2022), suggesting a detriment of the activity of the cortical route (which is mainly responsible for HSF processing). Moreover, the study also showed that surprised faces filtered either at LSF or at HSF were judged as less negative by older adults (OA) compared with younger adults (YA), revealing that when the stimulus is ambiguous in valence (i.e., surprised faces), OA judged the stimulus as less negative than YA. This evidence is in line on the one hand with the evolutionary theory suggesting that in younger persons the processing of negative stimuli is an automatic process specifically enhancing survivor mechanisms (eliciting fight or flight reactions); on the contrary, it can be seen as supporting the well-known "positivity effect," which is widely documented in aging as a higher sensitivity and priority in processing and recall information carrying positive emotion in OA compared with YA (Mather, 2016; Mather & Knight, 2005). The positivity effect has been explained as associated with the fact that, due to their limited temporal horizon of life, older persons try to avoid negative emotions and focus on positive experiences, as suggested by the so-called socioemotional selectivity theory (Carstensen et al., 1999, 2006). Moreover, this age difference has been confirmed in a memory task (Charles et al., 2003), with OA being more accurate in recalling pictures with positive than negative emotional contents and YA being more accurate in recalling pictures with negative than positive emotional contents.

The idea of a stronger activity of the cortical (vs. subcortical) route in aging has been recently confirmed in a neuroimaging study, showing a relationship between the positivity effect and the stronger activity of prefrontal areas, together with a reduced activity of subcortical structures (Petro et al., 2021). Nevertheless, when memory is called into question, evidence suggests that the activity of the subcortical route is crucial for a correct recognition of stimuli previously processed: In an incidental recognition task, emotional faces were recalled better than neutral faces, and this emotional memory enhancement was found to be particularly strong for stimuli filtered at LSF (subcortical route) compared with those filtered at HSF (Rohr et al., 2017). However, to the best of our knowledge, no evidence in this domain has been collected in aging.

Starting from these premises, the main aim of the present study was to assess the possible effect of aging on the activity of the dual route in an emotional face recognition task. To this aim, we presented emotional and neutral faces as unfiltered, filtered at LSF, and as hybrids to a group of YA and to a group of OA. After this encoding phase, we asked them to express an old/new judgment on unfiltered stimuli (recognition phase). We wanted to explore whether the spatial filtering manipulated in the encoding phase can affect memory in an old/new recognition task. We expected that emotional faces would be better recognized than neutral faces in both groups (thus confirming the emotional memory enhancement) and that stimuli with a positive emotion would be better recognized than those with a negative emotion, mainly in older participants (i.e., age-related positivity effect). Importantly, we aimed to obtain the first evidence of the effect of spatial filtering on memory in aging: Starting from the only evidence in this domain, collected with young participants (Rohr et al., 2017), we expected a better performance for LSF emotional stimuli in younger participants (subcortical pattern), but we hypothesized the opposite pattern in older participants, as found in previous perceptual tasks with filtered stimuli (Barber et al., 2022; Petro et al., 2021).

Method

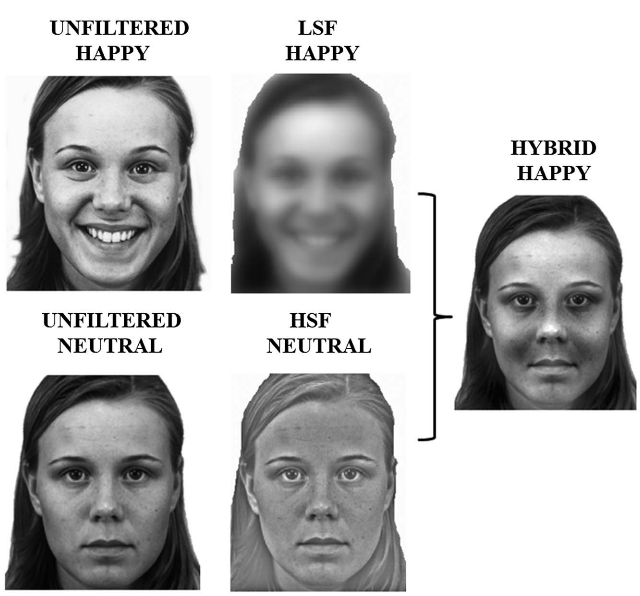
Participants

A total sample of 290 volunteers took part in the study. University students taking courses taught at the university in which the study was conducted were firstly recruited through social media ads and word of mouth, and they were asked to involve family and friends either under 35 or over 65 years old. They were informed that participation in the study was free and that they would not receive any compensation for their participation but would then take part in a debriefing lesson in which hypotheses, experimental procedure, and results would be explained. From the initial sample, six participants did not complete the task, and they were excluded from the analyses. The final sample consisted of 147 participants younger than 35 years (YA group: 99 females and 48 males, mean age ± standard error: 24.1 ± 0.32), and 137 participants older than 65 years (OA group: 83 females and 54 males, 73.2 ± 0.65). All participants were Caucasian, self-reported normal or corrected-to-normal vision, declared the absence of neurological and/or psychiatric conditions, and were unaware of the specific purpose of the study. Written informed consent was obtained before starting the experiment.

Stimuli

Stimuli were created from photographs contained in the Karolinska Directed Emotional Faces (Lundqvist et al., 1998), a database of faces with neutral and emotional expressions. Photographs in frontal view of 18 young female and 18 young male faces in happy, angry, and neutral expressions were selected and converted into grayscale images, measuring 5.2° × 5.3° of visual angle (260 × 270 pixels) seen at a distance of 72 cm. Then, all stimuli were manipulated using MATLAB software (MathWorks Inc., Natick, MA), obtaining one image filtered at LSF (one to six cycles per image, cpi; see Figure 1) and another image filtered at HSF (7–128 cpi). Hybrid faces were the same used by Laeng et al. (2010) in the pioneering study with these stimuli: They were created by superimposing the LSF of an emotional face (either angry or happy) to the photograph filtered at HSF of the same face with a neutral expression (Prete, Laeng, et al., 2018; Tommasi et al., 2021). By presenting all the basic emotional expressions as hybrid stimuli, Laeng et al. (2010) found that implicit emotional evaluations of (young) observers were strongly and significantly influenced by happiness and anger, and thus we decided to use these two expressions to maximize the expected effects of subliminal emotions.

Figure 1
Stimuli



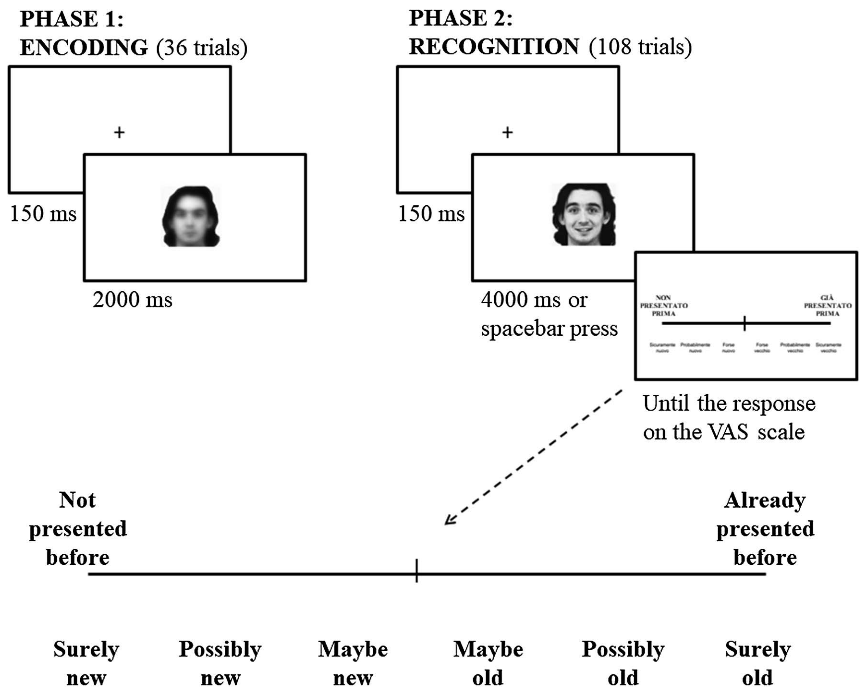
Note. Examples of stimuli presented as unfiltered (i.e., original stimuli), filtered at low spatial frequencies (LSF, 1–6 cpi), and hybrid, in which the LSF of an emotional face (e.g., LSF happy) are superimposed to the high spatial frequencies (HSF, 7–128 cpi) of the same person with a neutral expression (i.e., LSF happy + HSF neutral = hybrid happy).

Procedure

Stimuli were presented in the center of the screen (1,024 × 768 pixels) on a white background. Participants were asked to sit at 72 cm from their computer and to avoid movements for the duration of the task. They were also explained that the task was divided into two phases: a first passive viewing phase and a second active recognition phase. During the first phase (encoding), 36 facial stimuli were randomly presented: 12 stimuli were unfiltered, 12 were presented filtered at LSF, and 12 were hybrid. In each filtering condition, four stimuli were presented in neutral, four in happy, and four in angry expression, and for each emotional expression, half were female faces, and half were male faces (all were different identities). In each of the 36 trials, a black fixation cross was presented in the center of the screen for 150 ms, and it was followed by a facial stimulus presented in the center of the screen for 2000 ms. Participants were instructed to pay attention to each stimulus and to focus on both the identity and the emotional expression of the face, independently from its filtering, because in the second part of the task, they would be asked to recognize the identity/emotional expression just viewed, independently from the filtering (which would not have been applied in the second phase).

During the second phase (memory recognition), a total of 108 trials were presented: The 36 faces already shown in the encoding phase (i.e., same identity with the same emotional expression) were presented also with the two other facial expressions. In this phase, however, all stimuli were presented as unfiltered. For instance, the photograph of a person presented at LSF in happy expression during the encoding phase was presented unfiltered in the recognition phase, with (a) the original happy expression (hence, it had to be categorized as already viewed), (b) in neutral expression, and (c) in angry expression. Participants were required to categorize each stimulus as either already viewed (36 stimuli: same identity and same emotional expression) or new (72 stimuli: same identity but with a different emotional expression than in the encoding phase). In each trial of the recognition phase, after a black fixation cross was presented in the center of the screen for 150 ms, an unfiltered face was presented in the center of the screen for 4,000 ms or until a response was given. Participants were asked to press the spacebar as soon as they recognized the stimulus as already viewed or not viewed in the encoding phase. When the spacebar was pressed, the face disappeared and a Visual Analogue Scale (VAS) was presented in the center of the screen: Participants were instructed to use the mouse to select the position corresponding to their response, from 0 in the leftmost portion of the bar (surely new stimulus) to 100 in the rightmost portion of the bar (surely old stimulus; see Figure 2). A VAS was used instead of a dichotomic old/new choice to obtain a more sensitive response on a 0–100 continuum. To facilitate the task, six anchor labels were added under the response bar, from left to right: surely new, possibly new, maybe new, maybe old, possibly old, and surely old. Moreover, in the leftmost/rightmost part of the screen, two labels were added:

Figure 2
Procedure



Note. Schematic representation of the experimental procedure constituted of a passive encoding phase (on the left) and a recognition phase (on the right) in which the degree of certainty of recognition must be assessed on a Visual Analogue Scale (VAS). The lower portion of the figure shows the VAS: Participants had to express their ratings from the leftmost portion (rating 0) to the rightmost portion (rating 100) by moving the mouse cursor.

"not presented before" and "already presented before," respectively. When the mouse button was released, the response was recorded, and the next trial started. Before the experimental procedure, eight trials were presented to allow participants to become familiar with the stimuli, the procedure, and the response scale.

Presentation order of the trials was randomized within and across participants in both phases. Participants were instructed that they can have a short break between the two phases, to relax for a few minutes (no other tasks were administered during the break) and to start with the second phase when they were ready. The whole procedure was carried out in accordance with the principles of the Declaration of Helsinki, and it was approved by the institutional review board (protocol number: IRBP/22005). The paradigm lasted about 30 min, and it was shared and controlled by E-Prime Go software (Psychology Software Tools, Inc., Pittsburgh, PA).

Results

Data were automatically recorded on E-Prime Go server, and then they were downloaded and aggregated. Responses given on the VAS (from 0 = *surely new* to 100 = *surely old*) were used as the dependent variable. In the first analysis, the mean value of responses (from 0 to 100) given for "new stimuli" (those not presented in the encoding phase) and the mean value of responses given for "old stimuli" (those already presented in the encoding phase independently from the Filtering condition) were compared with 50 (the mean value of the VAS, ranging from 0 to 100) by means of single-sample t tests. Results confirmed that for both conditions, the responses significantly differed from chance, new stimuli: 44.8 ± 0.64, $t(283) = -8.15$, $p < .001$, small effect size with Cohen's $d = 0.48$; old stimuli: 51.4 ± 0.63, $t(283) = 2.2$, $p = .028$, small effect size with Cohen's $d = 0.13$.

Then, responses for stimuli already presented in the encoding phase (old stimuli) were used as the dependent variable in a $2 \times 3 \times 3$ analysis of variance, in which Group (YA, OA) was used as between-subjects factor and Filtering (Unfiltered, LSF, Hybrid) and Emotion (Neutral, Angry, Happy) were used as within-subjects factors. When needed, post hoc comparisons were computed using Duncan's test, and the significant threshold was set at $p = .05$. Table 1 shows the means and standard deviations for each condition in each group.

All main effects were significant: Group, $F(1, 286) = 4.93$, $p = .027$, $\eta_p^2 = 0.017$, showed higher scores, corresponding to a better recognition of stimuli already presented, in OA (52.95 ± 0.96) compared with YA (49.95 ± 0.83). Filtering, $F(2, 572) = 151.46$, $p < .001$, $\eta_p^2 = 0.37$, showed a better recognition for Unfiltered (60.30 ± 0.86) compared with Hybrid (47.81 ± 0.78) and LSF stimuli (46.09 ± 0.84; $p < .001$ for both comparisons). Emotion, $F(2, 572) = 60.33$, $p < .001$, $\eta_p^2 = 0.17$, showed a better performance for Neutral (57.43 ± 0.78) compared with both Angry (48.31 ± 0.89) and Happy stimuli (48.46 ± 0.87).

The interaction between Group and Emotion was significant, $F(2, 572) = 11.66$, $p < .001$, $\eta_p^2 = 0.04$, and post hoc comparisons

Table 1
Descriptive Statistics

	New stimuli			Old stimuli								
	Unfiltered			Unfiltered			LSF			Hybrid		
Age group	Neutral	Angry	Happy	Neutral	Angry	Happy	Neutral	Angry	Happy	Neutral	Angry	Happy
YA												
M	51.77	36.06	38.52	66.02	57.23	59.04	47.91	44.72	37.53	61.71	37.73	37.67
SD	10.58	13.53	12.74	18.32	21.86	19.53	18.73	18.39	19.64	17.03	19.15	18.53
OA												
M	52.59	42.83	47.58	60.58	58.03	60.80	50.41	47.40	49.15	57.73	45.12	47.37
SD	12.10	14.62	14.06	19.62	21.31	20.39	18.42	22.24	19.88	19.90	19.36	20.77

Note. The mean (*M*) and standard deviation (*SD*) for each condition on the Visual Analogue Scale (from 0 = *surely new* to 100 = *surely old*), for younger adults (YA) and for older adults (OA). LSF = low spatial frequencies.

confirmed a better recognition for Neutral compared with Angry and Happy faces in both groups (for all comparisons: $p < .002$) and, importantly, showed that OA recognized Happy stimuli better than YA ($p < .001$).

Group also interacted with Filtering, $F(2, 572) = 7.11$, $p < .001$, $\eta_p^2 = 0.024$, confirming a better performance for Unfiltered compared with LSF and Hybrid stimuli in both participants' groups (for all comparisons: $p < .001$) and revealing that the performance of OA was higher compared with that of YA for both LSF ($p = .001$) and Hybrid stimuli ($p = .018$).

Filtering and Emotion significantly interacted, $F(4, 1{,}144) = 24.89$, $p < .001$, $\eta_p^2 = 0.08$: post hoc comparisons showed that in all Filtering conditions, Neutral stimuli were better recognized than Angry and Happy stimuli ($p < .02$) and that only in LSF condition, Angry faces were recognized better than Happy faces ($p = .024$). Furthermore, Neutral faces were better recognized when presented as Unfiltered compared with Hybrid ($p = .005$) and when presented as Hybrid compared with LSF ($p < .001$). Angry faces were better recognized when presented Unfiltered compared with LSF and LSF compared with Hybrid (for both comparisons: $p < .001$). Happy faces were better recognized when presented Unfiltered compared with both LSF and Hybrid (for both comparisons: $p < .001$).

Finally, the interaction among Group, Filtering, and Emotion was significant, $F(4, 1{,}144) = 2.50$, $p = .041$, $\eta_p^2 = 0.009$; see Figure 3. Post hoc comparisons revealed that for Neutral faces presented Unfiltered, YA showed a higher recognition compared with OA ($p = .036$), with no difference for Angry and Happy Unfiltered stimuli. However, OA outperformed YA for Happy faces presented at LSF ($p < .001$) and for both Happy and Angry faces presented as Hybrid ($p < .001$ and $p = .006$, respectively). Moreover, within the YA group, Unfiltered and Hybrid faces were recognized better when presented Neutral compared with both Angry and Happy, whereas LSF faces were recognized better when presented as either Neutral or Angry compared with Happy (for all comparisons $p < .001$). Within OA, difference emerged only for Hybrid faces, with a lower performance for both Angry and Happy faces compared with Neutral stimuli (both $p < .001$).

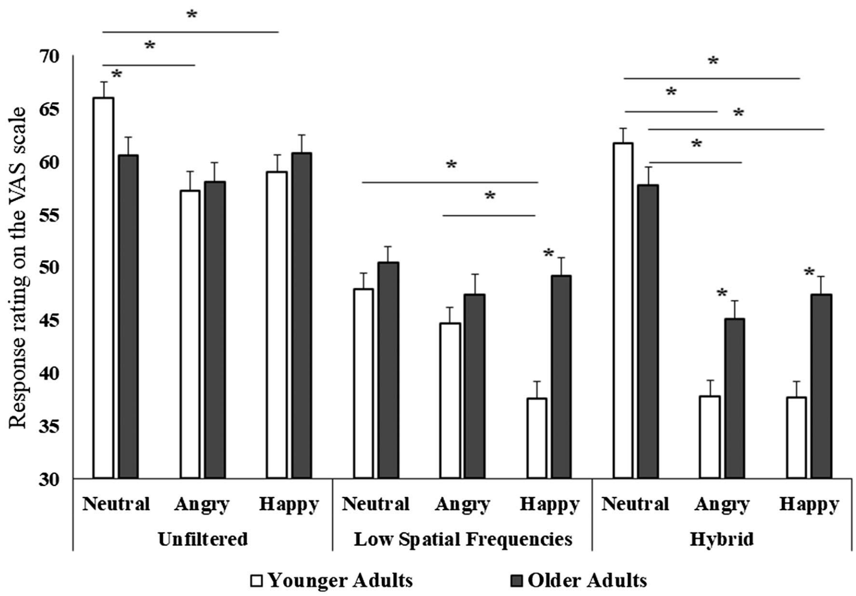
Finally, in YA, Neutral faces were recognized better when presented Unfiltered compared with Hybrid and Hybrid compared with LSF (both $p < .02$), Angry faces were recognized better when presented Unfiltered compared with LSF and LSF compared with Hybrid, whereas Happy faces were recognized better when presented Unfiltered compared with both LSF and Hybrid (all $p < .001$). In OA, Neutral faces were recognized better when presented Unfiltered and Hybrid compared with LSF, whereas Angry and Happy faces were recognized better when presented Unfiltered compared with both LSF and Hybrid (for all comparisons $p < .001$).

Discussion

The dual-route model is a well-established model widely supported by neuropsychological and cognitive evidence (LeDoux, 1996), according to which emotional stimuli are subjected to a parallel processing through a subcortical route (LSF, fast and implicit analysis) and a cortical route (HSF, slow and conscious analysis). How each route works in aging is a research field that received little attention so far, and the present study aimed at shedding light on this topic, with a particular focus on memory recognition of emotional faces presented at LSF. As reviewed above, at a perceptual level a stronger cortical (vs. subcortical) activity was found in aging, together with a reduced activity of the subcortical pathway (Petro et al., 2021). These findings led to conclude that in aging the cortical-conscious route is responsible for a top–down, controlled response of emotional stimuli, also related to the well-known positivity effect (Di Domenico et al., 2015; Petro et al., 2021; Reed & Carstensen, 2012). Concerning memory recognition, however, no evidence describes the functioning of the two routes in aging, even if a better performance in recognizing emotional faces filtered at LSF (vs. HSF) was found in an incidental recognition task in young participants (Rohr et al., 2017), suggesting a predominant role of the subcortical route in encoding emotional stimuli. Surprisingly, the main result of the present study revealed that older participants outperformed younger participants in recognizing emotional faces, specifically when the subcortical route was activated in the encoding phase because stimuli were presented filtered at LSF or as hybrid.

The first result of the present study is that in the "old"/"new" recognition task exploited here, participants recognized facial stimuli already presented (i.e., "old" stimuli) with a performance higher than the chance level, as shown by *t* tests. Even if the effect sizes of this first analysis are small ($d < 0.50$), this result revealed that—although participants correctly recognized old stimuli—the task was difficult and this can be due to the filtering procedure used here: To test the dual-route model, in the encoding phase facial stimuli were presented as either unfiltered, filtered at LSF, or hybrid, whereas in the recognition phase, all stimuli were presented unfiltered. This filtering

Figure 3
Group × Filtering × Emotion



Note. Interaction among Group (younger adults, older adults), Filtering (Unfiltered, low spatial frequencies [LSF], Hybrid), and Emotion (Neutral, Angry, Happy) on the VAS (from 0 = *surely new* to 100 = *surely old*) for stimuli already presented in the encoding phase (higher scores correspond to a higher level of recognition and thus to a better performance). Moreover, the comparisons among the Unfiltered, LSF, and Hybrid conditions within each group and each emotional expression were all significant, but they are not represented by means of asterisks (see the text). VAS = Visual Analogue Scale.
Bars represent standard errors, and asterisks represent the main significant post hoc comparisons (* $p < .05$).

difference between the two sessions, together with the fact that a correct response required participants to processed both identity and emotional expression, makes the task difficult, especially in correctly recognizing stimuli already presented (old stimuli), for which both identity and emotional expression must be recognized, independently of the filtering condition. In fact, the following analysis showed an overall better performance for stimuli presented as unfiltered compared with both LSF and hybrid stimuli, and this confirmed that the higher recognition for unfiltered stimuli can be justified by the fact that in this condition broadband images were shown in both phases, so the same stimulus is presented during both the encoding and the recognition step. However, differently from the previous evidence using an incidental memory task (Rohr et al., 2017), we informed participants that they would be administered a following recognition session, so they were explicitly required to pay attention and memorize facial stimuli independently of their possible spatial filtering. This difference can explain the divergent pattern of results found by Rohr et al. (2017; better recognition for LSF stimuli) and in the present study, in which the better performance was recorded for unfiltered stimuli.

Moreover, differently from the starting hypotheses, we found an overall better performance by older compared with younger participants, in contrast with the well-known age-related decline in memory performance (Fraundorf et al., 2019), as well as a higher recognition rate for neutral than for angry and happy faces, disconfirming the expected emotional memory enhancement (Kensinger et al., 2007; Mammarella et al., 2016). These unexpected findings are better explained by specific interactions between factors. For instance, even if neutral faces received a higher recognition by both groups, OA recognized happy faces better than YA, suggesting—at least partially—the positivity effect in aging (Ceccato et al., 2022; Mammarella et al., 2017; Reed & Carstensen, 2012).

Importantly, the three-way interaction among group, filtering, and emotion confirmed the expected better performance by younger compared with older participants for the "baseline condition," namely, for neutral faces presented unfiltered, but the opposite pattern emerged for emotional hybrid faces and for happy LSF stimuli, with OA showing higher recognition than YA. This interaction is particularly interesting because it confirms that when only the cortical route is activated (i.e., the baseline condition with neutral unfiltered faces), the memory skills of young participants are better than those of older participants, ensuring that the task was correctly understood and carried out and, importantly, confirming the expected higher memory skill by young participants (Fraundorf et al., 2019). However, when the activity of the subcortical route is required for the processing of emotional information (LSF and hybrid stimuli), OA revealed a facilitation in the recognition of the emotional expressions, especially happy faces, in line with the positivity effect in aging. In fact, if on one hand OA outperformed YA for angry hybrid faces, on the contrary, this pattern is significant for happy faces presented both at hybrid and at LSF. This difference between the angry and the happy expression can be considered in line with the evidence according to which happiness is a "distal" emotion, based on LSF processing, as opposed to anger, which would be a "proximal" emotion, based on HSF (Smith & Schyns, 2009). This argument can explain the reason why the presentation of angry faces at LSF did not impact the performance due to the fact that a deeper analysis of such proximal emotion needs the HSF to be properly processed.

The interaction between filtering and emotion confirmed no difference in the recognition of happy faces presented as hybrid and at LSF, whereas angry faces were better recognized when presented at LSF than as hybrid, again confirming that the neutral HSF shown in hybrid stimuli reduced the performance in the whole sample. Independently of emotions, also the interaction between group and filtering condition confirmed that OA recognized better than YA both LSF and hybrid stimuli, revealing that the activity of the subcortical route during the encoding phase enhances the performance of older participants in the recognition phase. This result is crucial for the aim of the present study even if it did not match our experimental hypothesis: Basing on a perceptual task, in fact, we hypothesized OA to be more efficient in processing HSF (Barber et al., 2022; Petro et al., 2021). It was found that, compared with YA, OA show a reduced subcortical activity, involving the amygdala, during the processing of emotional stimuli (Leclerc & Kensinger, 2011). Differently from perceptual tasks, however, the present task required stimuli presented in the encoding phase to be retained in memory for a successive recognition phase. Using an incidental recognition task with young participants, Rohr et al. (2017) found that emotional stimuli filtered at LSF were recognized better than those filtered at HSF: The present results confirmed a better performance when emotional content was presented at LSF (subcortical route), showing that this evidence is stronger in OA than in YA.

Further studies are needed to clarify to which extent this facilitation of the subcortical route's activity is generalizable in aging. For instance, stimuli used here did not allow to clarify whether this facilitation is specific for emotional faces, or it can be obtained also with different categories of visual stimuli (e.g., words, pictures). Moreover, in the present study, a 0-to-100 VAS was used to record participants' responses, but it could be useful to carry out an old/new recognition task in which a dichotomic old/new response is collected. If the stronger activity of the subcortical route in aging would be confirmed, it can be exploited as evidence useful to develop specific memory protocol to preserve and strengthen memory skills in healthy and pathological aging.

The absence of an emotional memory enhancement in younger participants is an unexpected result, and we hypothesize that it can be due to the difficulty in focusing on the emotional content of the facial stimuli in the encoding phase, due to filtering procedure. Moreover, in this case, further studies should explore this possibility by presenting unfiltered stimuli in the encoding phase and by presenting LSF and hybrid stimuli in the recognition phase. In this case the role of each route in encoding versus recognition phase can be disentangling in a clear way. Finally, a limitation of this study is the uncontrolled role of the arousal level of the stimuli. As specified in the stimuli description, we used emotional expressions and stimuli already exploited in previous studies with hybrid emotional faces (Laeng et al., 2010; Prete, Laeng, et al., 2018; Prete et al., 2019). It should be noted however that some evidences suggest a different impact of arousal at different ages (Dolcos et al., 2014; Nielsen et al., 2008), even if some other evidences are inconsistent with this model (Abiodun et al., 2024), so that future studies in this domain should also disentangle the possible effects of arousal on the emotional processing at different ages, as well as on its possible effect on the activity of the cortical versus subcortical route during the lifespan.

To conclude, the present study explored memory recognition of emotional faces through the two routes of emotion processing in younger and older participants. No previous evidence investigated this issue at different ages, but at a mere perceptual level, some findings were described in this domain. In particular, a study found a reduced activity of the subcortical route in aging (Petro et al., 2021), and in a recent go/no-go emotional task (Prete et al., 2024), it has been found that independently of low or high spatial filtering of emotional faces, YO outperformed OA in emotion detection. These findings, which are not specific for LSF versus HSF, suggest a general decrement in emotion detection in aging, thus involving both the cortical (HSF) and the subcortical (LSF) route (Prete et al., 2024). The present results shed a new light on this topic, with the first evidence of a better performance by older than by younger participants when in the encoding phase emotional faces are presented filtered at LSF or hybrid. This evidence indirectly hints a strong activity of the subcortical route in aging in a recognition task, suggesting that memory can be specifically enhanced (independently of a perceptual facilitation that seems not to be at the basis of the results; Prete et al., 2024), with a special facilitation for the positive valence emotions, thus linking the age-related positivity effect in the memory domain with the activity of the subcortical route.

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