Differences in face recognition at a younger and higher age

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Frankfurt, 09.01.2017 Andreas Schaich

Contents

Abstract

Faces are thought to be processed primarily according to their configurations which is inferred from comparisons with non-facial stimuli. While the whole (face) seems to be more than the sum of its parts, the same does not apply to objects which are processed analytically according to their featural information. A recent recognition model stresses the importance of certain visual information within facial stimuli. By applying a specific filtering technique, stimuli can be generated that are restricted to contain information of only a certain orientation. Dakin and Watt (2009) reported greatest recognition performance with faces that only contained horizontally aligned information with accuracy continuously declining at vertical. Furthermore, they showed that, compared with images of natural scenes, horizontal contours within faces have an unusual tendency to fall into vertically co-aligned clusters which were labelled biological 'bar code' referring to a highly constrained one-dimensional code. Consecutive research tested for face-specific processing by comparing faces and objects that displayed information of different orientations. Results suggested configural processing only for faces that contained horizontal information (Goffaux & Dakin, 2010). The findings contribute important insight on a still unanswered question in face processing research: what information is extracted from faces for recognizing them.

Despite the importance of remembering human faces on a daily basis, this ability seems to develop disadvantageously over lifetime. Decreased accuracy cannot be attributed to decreased general cognitive ability (Hildebrandt, Wilhelm, Schmiedek, Herzmann, & Sommer, 2011) and slower reactions times are assumed to be a product of decision making rather than sensory speed (Habak, Wilkinson, & Wilson, 2008). Considering the amount of published work on face recognition, there is a lack of studies available assessing this important ability at a higher age. New theoretical concepts are rarely examined with older participants, apparently assuming their general validity. The current dissertation tries to help fill this gap by assessing the importance of horizontal information from a developmental perspective comparing younger and older adults under different experimental variations. The first study showed, that presenting older participants with horizontally filtered faces has a disproportional negative impact on recognizing younger unfamiliar faces suggesting differential processing mechanisms, since recognizing stimuli that only contained vertical information did not differ between age groups. On this basis, the following study manipulated the presented stimulus material, since some evidence suggests that own-age faces are more easily recognized compared to faces of other ages, which is referred to as "own-age bias". Therefore, the second study

systematically assessed the impact of stimulus age on recognition sensitivity. Moreover, encoding modalities were varied by providing increased exposure duration to the stimuli. The results of the first study were replicated, as older participants' performance was still poor at recognizing younger faces, independent from encoding modalities. However, similar face recognition sensitivity compared to younger adults was observable when filtered faces of the older adults' own age had to be recognized. Interestingly, correlations between recognizing filtered and unfiltered faces were obtained for younger adults but not for older adults suggesting age variant processing of horizontal information. The last study assessed the importance of horizontal information with stimulus material familiar to the observer. Although research highlights differences between recognizing unfamiliar and familiar stimulus material, this factor is often not considered by contemporary research. By presenting participants with their own faces, a stimulus of greatest individual familiarity was chosen. The superiority of own face recognition over other familiar material is referred to as "self-face advantage" and has been shown in comparison with personally familiar faces (Keyes & Brady, 2010) and famous faces (Caharel et al., 2002). While younger adults indeed recognized their self-faces better compared to famous faces independent from stimuli being filtered or unfiltered, older participants displayed a completely different pattern including the inability to recognize their filtered self-faces. Again, significant associations were obtained between filtered and unfiltered recognition conditions suggesting convergent processing mechanisms for younger adults but not for the older age group.

This dissertation provides a first insight in the divergence of response behavior in older adults with a recent face processing model. While the obtained data undermine the importance of horizontal information in younger adults by replicating and extending previously published work, a profoundly different type of processing is suggested at a higher age which largely relies on low-level pictorial information due to the inability to process horizontally filtered faces configurally. Specifically, it is suggested that with age, focusing on aging-salient features with configural processing disrupted may function as a critical source of diagnostic information which can ultimately result in performance similar to younger adults.

1. Introduction

When asked: “What kind of research do you do?” I can easily provide the information “I assess face recognition in younger and older adults!” which is often directly accepted and appreciated by the recipient while accompanied by a nod: “Yes, that is an important issue!”. Sometimes a question would follow: “and what exactly do you do?”. Now the tough part begins: “I assess a recent face recognition model which suggests that horizontal information is especially important when recognizing faces. However, this seems to hold true only for younger adults. In older adults, processing of this type of information seems to be somehow disrupted (as has been found in this dissertation)”

Someone (Professor Knopf) once told us (Ph.D. students) we should be able to summarize our research in a few sentences at any given situation. If I were to carry an image of Figure 1, I would continue: “this means that younger adults recognize the identities from 1d and 1e (which only contain horizontal information) in Figure 1 much better than older adults do (assumed they are familiar with the two celebrity faces in the first place). Recognizing images 1g and 1h (which only contain vertical information) is equally challenging for both age groups. Consequently, there seem to be age differences when it comes to processing horizontal information.” “Well, ok, I get it. Older adults can’t recognize ‘horizontal information’. But what is ‘horizontal information’”. “Good question! But let’s start with faces in general.”

1.1 Perceiving, processing and recognizing faces

Faces are incredibly interesting inferring from the amount of research that has been published on the topic. Hole and Bourne (2010) who wrote one of the books that accompanied me over the last four years, reported well over 100.000 published journal articles when typing “face recognition” into the search engine which brings me to a short excursion to the terminology used by researches and has nicely been addressed by O’Toole, Wenger, and Townsend (1998): “the term ‘recognition’ has been used in multiple domains to mean multiple things, including identification (e.g., ‘recognizing’ a face as being someone in particular), discrimination (e.g., that the particular face is the same or different from some other face), and the task of determining whether one has seen a particular face before (e.g., ‘recognizing’ a face as being one that was seen in an earlier encounter)” (p. 5). Clearly, different cognitive abilities are being targeted ranging from highly “perceptual” tasks with very little mnemonic components to tasks that primarily target face memory – a circumstance that will be addressed below in more detail. The sheer number on face recognition papers gives the reader a sense of how many different models, effects, and factors have been discovered and assessed so far. I will therefore not try to introduce the field of face recognition, but only provide a brief overview focusing on the question why science can profit from studying faces quickly leading to the three studies I conducted.

I am not sure, whether this has been assessed before, but if a participant of basically any psychological experiment was given the choice to look at different stimuli from the following categories: planes, houses, toys, or faces; my prediction would be that the majority would chose faces. In fact, I cannot think of any stimulus that would provide a greater variability. Faces differ on so many dimensions, starting with the shape of the head, color of the hair or skin, size of ears or chin that already 100.000 potential outcomes would be possible if each feature would only encompass 10 different manifestations. And as we will see below, the properties I just mentioned are not even the main characteristics of faces as they are (only) part of the outer facial structure with little contribution to identity. Johnson (2011) states: "I have little interest in face perception for its own sake […]. I have always viewed face perception as the ideal case study example for understanding the deeper principles underlying human neurodevelopment" (p. 3). The question whether face recognition develops as a result of experience or reflects an ability which is present from birth has been part of an ongoing nature versus nurture debate. In "The Expression of the Emotions in Man and Animals", Charles Darwin (1872) argues for an innate ability which is expressed in an observation he made on his first-born infant "[…] who could not have learnt anything by associating with other children, and I was convinced that he understood a smile and received pleasure from seeing one, answering it by another, at much too early an age to have learnt anything by experience" (p. 117). Studying face processing "in earnest" started with a publication by (Fantz, 1963) who showed that newborns preferred to look at schematic faces compared to a bull's - eye pattern. This finding may not sound that astonishing, however it initiated the dispute, whether faces are special, or not. The domain-specificity-hypothesis proposes, that faces are processed via specific mechanisms carried out by specialized brain parts in the fusiform gyrus (Kanwisher, McDermott, & Chun, 1997). This fusiform face area (FFA) was shown to be more active (fMRI), when subjects viewed faces compared to common objects like houses. Contrary, Gauthier, Skudlarski, Gore, and Anderson (2000) showed recruitment of the FFA in bird and car experts when presented with respective stimuli suggesting expertise-based specialization of the fusiform gyrus - not face-specificity.

An approach that has extensively been used by psychologists is to find out how something works by examining how it copes with different manipulations of the input to the processes involved (Hole & Bourne, 2010) which is directly applicable to face recognition research. In other words: we still do not actually know how faces are processed, however, we do know a lot about which factors have an impact on face processing.

Early findings reported some parts of a face as being more important than others with the eye region providing most salient information followed by the nose and mouth region (Chung & Thomson, 1995). Critically, faces were conceived of as being collections of features with research focusing on developing feature salience hierarchies (Hole & Bourne, 2010). Feature-based processing is widely accepted to contribute to recognizing faces and its importance is to date reflected in e.g., the assessment of fixation patterns (Peterson, Lin, Zaun, & Kanwisher, 2016). However, in a second phase, appreciation of the importance of configural processing became more apparent basically stating that the whole (face) is more than the sum of its parts. A lot of psychological studies suggest that faces are processed primarily according to the configural information within them, other than objects, which are thought to be processed in a feature-based manner which is often referred to as analytic processing. This can be envisioned, by turning a face upside down which results in lower recognition accuracy compared to upright faces and was first shown by (Yin, 1969). An analogous decrease in performance with objects is however not observable. This effect (titled "Face Inversion Effect", FIE) has been replicated countless times and is taken as one of different empirical paradigms that manipulate configural and analytic perception of faces (Tanaka & Gordon, 2011).

1.2 Models of face processing

From general day-to-day observations, people may assume that they are good or bad face recognizers presumably inferring from experiences like recognizing someone they just met while others might be more familiar with asking the question: "have we met before?". Despite obvious constructs like similar attention to the stimulus, variables like context (Davies & Milne, 1983) or distinctiveness (Going & Read, 1974), meaning that some faces are easier to recognize than others, have shown to be decisive factors.

1.2.1 The multidimensional face space model

Abovementioned ideas were systematically assessed and published in Valentine's (1991) "Multidimensional Face Space Model (MFSM)" which integrated distinctiveness, among other factors trying to explain how faces are represented in memory. Specifically, each (familiar) face is suggested to be stored in values on different facial dimensions, meaning e.g., some noses would be longer, some shorter constituting the nose dimension, another might be how far eyes are apart etc. resulting in an n-dimensional face space. Ease of recognition of a given face would then be determined by the proximity of neighboring faces in face-space (Hole & Bourne, 2010). Valentine himself describes his model as a useful heuristic framework that helps investigating face recognition foremost explaining why faces that are more average (closer together) are more easily confused than faces that are further apart in face space. Following this line of thought, every person would have a personal multidimensional face space which develops over lifetime.

1.2.2 The Bruce and Young model of face processing

The most influential face processing model to this day was introduced by Bruce and Young (1986). It assumes that face recognition involves several separate processes that occur in discrete successive stages. In total, seven distinct types of information are suggested to be derived from seen faces. The first two were labelled pictorial and structural codes which originates from research conducted by Bruce (1982). In a first experiment, she assessed the effect of changing unfamiliar faces on recognition accuracy and latency resulting in best performance when unfamiliar faces were unaltered (i.e., exactly the same images were presented) followed by changes in pose and worst performance (slower and less accurately) with both pose and expression altered. The author argued that identical images enabled participants to remember both information specific to the image (pictorial codes) and information of the face which she referred to as structural codes. With two aspects (expression and pose) altered, participants had to rely on structural codes, which had not developed yet for the faces presented. In a second experiment, Bruce (1982) added highly familiar faces resulting in yet again the same performance pattern with unfamiliar faces. Alterations on the familiar faces however only impacted reaction times but with accuracy at ceiling level. Moreover, familiar faces were recognized faster and more accurately than unfamiliar faces. Consequently, participants seemed to already have fully developed structural codes allowing them to compensate for pictorial changes. Therefore, as pointed out by Bruce and Young (1986) experiments that utilize the same face images throughout the experiment tells us something about picture memory but little about face recognition, a circumstance that is even found in many studies today (Hole & Bourne, 2010). Bruce and Young (1986) suggest that a structural code is formed and stored only after repeated exposure to a face across a variety of expressions and angles. Successive stages comprise processing of visually derived semantic, identity-specific semantic, name, expression and facial speech codes. Importantly, recognition of familiar faces involves matching the products of structurally encoding a given face stimulus and previously stored structural codes. The authors describe that the appearances of familiar faces are held in memory as “Face Recognition Units, FRUs”. An activation of this unit will occur irrespective of viewing angle when the face is seen, but only if a threshold level of activation is reached that exceeds all other FRUs. This results in a feeling of familiarity signaling that the face has been encountered before followed by accessing identity-specific semantic codes and retrieving subsequently name codes. Until today, the model by Bruce and Young has been incredibly influential in the field and has shown consistent with many subsequent publications, both psychological and neuropsychological.

1.2.3 The barcode hypothesis

While the past two decades of face processing research focused on the role of faces' configurations as a guide to recognition, a third wave of research might ultimately hold the key to answering the question of how we identify individuals on the basis of their faces (Hole & Bourne, 2010). One recent theory states, that the key information of human faces is aligned horizontally and was even reported by a major German newspaper (Welt.de) covering the groundbreaking finding of two British Researchers on human perception (Möckel, 2009). Dakin and Watt (2009) introduced a filtering technique that selectively removes all visual information of an image but those restricted to certain orientation ranges which ultimately enables researchers to simulate what information would be passed by V1 neurons (Hubel & Wiesel, 1968) tuned to a specific visual structure. What the filtering process does, is breaking down any given visual stimulus to its basic components. Orientation information can then be restricted by Fourier transforming them and multiplying the Fourier energy with orientation filters (wrapped Gaussian profile with a standard deviation of 20°) allowing only information of a particular orientation to pass. The results of this process are depicted in Figure 1: for the faces of the middle row only horizontal information was allowed to pass, while images 1g - 1i solely contain information that is aligned vertically.

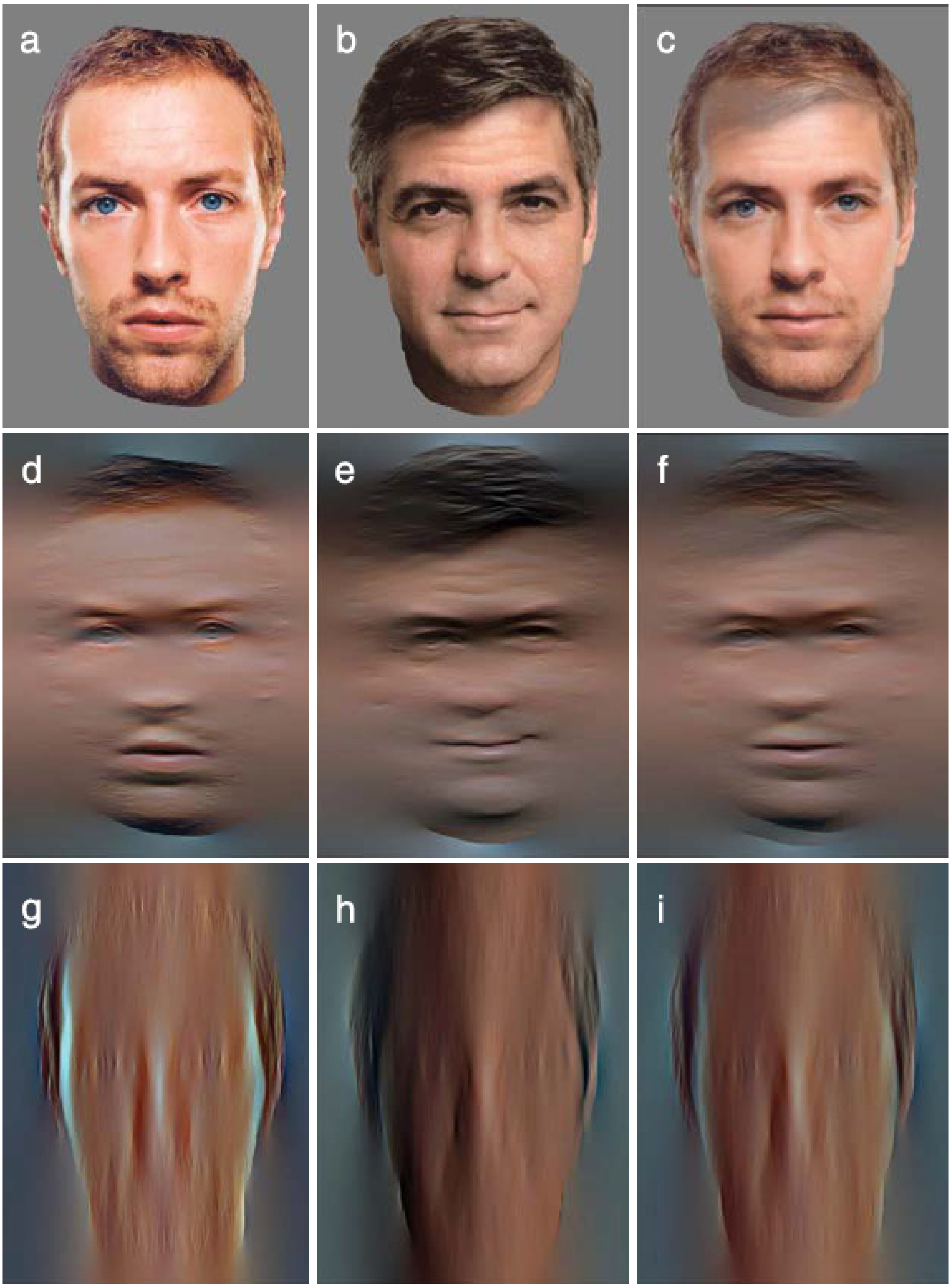

Figure 1. (a, b) Original face images and (c) their morphed average. (d–f) Horizontal and (g–i) vertical information contained in the three face images (bandwidth is σ = 20°). Original Figure available under http://jov.arvojournals.org/article.aspx?articleid=2193426.

The authors observed greatest face recognition performance with horizontal facial information compared to all other alignments. Moving from horizontal to vertical, sensitivity continuously declined reaching lowest performance at vertical alignments. Since horizontal contours tend to fall into vertically aligned clusters, which was only observable for faces but not for objects or natural scenes, this clustering was labeled biological 'bar code' referring to a highly constrained one-dimensional code which provides foremost potential computational benefits and might improve contemporary computerized recognition software (Möckel, 2009). Essentially, only this type of information is necessary to make a familiar decision when presented with a face we are actually familiar with (Dakin & Watt, 2009).

In a second study, Goffaux and Dakin (2010) extended prior findings by showing that face-specific (configural) processing was being used when presented with stimuli that only contained horizontal information, which in contrast was not the case for stimuli that only contained vertical information. Among different face-specific measurement paradigms, the authors presented participants with different stimuli (faces, cars, natural scenes) that were either presented upright or inverted (orientation factor). Furthermore, stimuli either contained only vertical information, only horizontal information, or both vertical and horizontal information (filter factor). Results confirmed a FIE only for faces but not for cars or scenes. Specifically, upright face recognition was better than inverted face recognition, when horizontal information or horizontal and vertical information was available but not when only vertically aligned features were visible.

In summary, the authors had shown that familiar faces can be identified correctly, when only horizontal information is available (Dakin & Watt, 2009) and what makes faces special stimuli, is still present, when horizontal information is provided but not when only vertical information is given (Goffaux & Dakin, 2010). According to Hole and Bourne (2010), thinking of faces as barcodes has advantages by providing a way to quickly and effectively detect faces in the environment. Furthermore, it would also explain why inversion impairs face recognition, as this manipulation produces bar codes that do not match the specifications of an upright face (i.e., light and dark regions would be in the wrong order).

1.3 Differences between the processing of familiar and unfamiliar faces

As described above, there is something different or special about faces which is foremost inferred from comparison with objects. For example, while objects are categorized more quickly on a basic level (e.g., “dog”) than on subordinate levels (e.g., “collie”; D’Lauro, Tanaka, & Curran, 2008), (familiar) faces make a notable exception as they are categorized as quickly and accurately (“Bob”) as on the basic level (“human”). As pointed out in the beginning, one of the problems with face recognition research is constituted by inconsistent terminology. Recognizing a face implies prior exposure to the stimulus which is obviously given when it comes to persons we are personally familiar with. However, the majority of studies conducted comprise of stimulus material unfamiliar to the participant. Though this makes sense, because it ensures similar baseline familiarity with the material, a number of studies highlights differences between recognizing familiar and unfamiliar faces. For familiar faces, Tong and Nakayama (1999) introduced the term “robust representations” which are proposed as “highly overlearned faces that are encountered under a variety of stimulus conditions and contexts”. In terms of Bruce and Young’s model, a FRU consists of familiar faces stored in structural codes. How robust those representations are, was demonstrated by Burton, Wilson, Cowan, and Bruce (1999) presenting participants with videos of surveillance cameras with poor resolution displaying fellow students on the one side and unfamiliar persons on the other. Analogous to the results reported by Bruce (1982) even slight alterations to unfamiliar faces resulted in very poor recognition while participants performed very well at identifying faces they were personally familiar with. Those quantitative differences have been reported many times including faster and more accurate recognition with familiar faces (Campanella, Hanoteau, Seron, Joassin, & Bruyer, 2003; Ellis, Shepherd, & Davies, 1979). Performance differences in recognizing unfamiliar and familiar faces have been found with tasks in memory and perception (Johnston & Edmonds, 2009). The fallibility of memory for unfamiliar faces is especially evident in eyewitness studies (Memon, Hope, & Bull, 2003; Reynolds & Pezdek, 1992; Shapiro & Penrod, 1986) which involves matching a live (unfamiliar) person to an image. But likewise, in face matching tasks, where the viewer has to determine whether simultaneously presented images (thereby minimizing the memory component) display the same person, participants perform with high error rates when faces are unfamiliar but are highly accurate when the persons to be recognized are familiar to the viewer (Burton et al., 1999; Megreya & Burton, 2006). Burton et al. (1999) reported error rates of 30% in a matching task where targets had to be identified in an array of 10 faces. Interestingly, the target face to be matched only differed to the array insofar that different cameras were being used - critically not allowing pictorial information to be processed. Consequently, several studies highlight qualitative differences between familiar and unfamiliar faces, suggesting they are represented differently and should therefore be considered as two different categories (Johnston & Edmonds, 2009). When recognizing familiar faces, internal features (eyes, nose, and mouth) were shown to be more important than external features (outer face shape and hair), while both types of features approximately contribute equally to recognition of unfamiliar faces (Ellis et al., 1979; Johnston & Edmonds, 2009; Young, Hay, McWeeny, Flude, & Ellis, 1985). Despite behavioral data, other lines of research support the notion of qualitative differences between processing unfamiliar and familiar faces such as different neural pathways (Natu & O'Toole, 2011) and interhemispheric cooperation for familiar but not for unfamiliar faces (Mohr, Landgrebe, & Schweinberger, 2002). Strong results suggesting qualitative differences were reported by Megreya and Burton (2006). The authors reported high correlations between matching unfamiliar faces presented upright and inverted famous faces, however, no associations between inversion and upright presentation within the category of familiar faces. Since inversion has shown to primarily disrupt configural processing, their results suggest that in unfamiliar face recognition, configural information is not used.

1.4 Face processing at a higher age

While some researchers propose that face processing is mature as early as after 4 years of experience with faces (de Heering, Rossion, & Maurer, 2012), others report ongoing recognition improvement until the age of 30 (Germine, Duchaine, & Nakayama, 2011). As the number of seen faces likely increases over the course of life, it seems plausible that face recognition becomes better or remains stable with age. Despite the interest in face recognition research, studies on face recognition at a higher age constitute a relatively small share of all the publications. Analogous to the question whether faces are special compared to other objects, aging might have a different effect on the ability to recognize either stimulus. To this point, an aging-specific face recognition theory cannot be established. What we do know is, that the processes involved in face recognition, i.e., configural processing, is likewise applied by older adults (Diamond & Carey, 1986; Farah, Wilson, Drain, & Tanaka, 1998; Meinhardt-Injac, Persike, & Meinhardt, 2014a). Although holistic processing, which integrates information across the face, has recently shown to be substantially delayed in older adults (Wiese, Kachel, & Schweinberger, 2013) the majority of published research indicates that the basic processing mechanisms involved in face recognition seem to be preserved in older adults, but become less efficient.

1.4.1 Inflated false alarms in older adults and slower latency

A finding, that has repeatedly been reported, is the tendency of older adults to falsely accept new faces as someone previously seen (Edmonds, Glisky, Bartlett, & Rapcsak, 2012; Lee, Smith, Grady, Hoang, & Moscovitch, 2014), which will be explained in the following. Aside reaction time, target detection sensitivity is the primary dependent variable used in measuring face recognition performance, usually in form of *d'*, which can for example be calculated as $d' = Z(\text{hit rate}) - Z(\text{false alarm rate})$ (See e.g., Macmillan & Creelman, 2004).

A face recognition experiment assessing face memory might look like this: A participant is presented with 20 different faces, which are displayed consecutively for let's say 5 seconds. After this learning phase, each of the 20 faces would be presented again but another 20 faces would be added. The participant would then be instructed to respond as quickly (first dependent variable) and as accurately (second dependent variable) as possible by deciding whether a given stimulus was previously presented in the learning phase (hit) or not (reject). If a participant falsely identifies a face as previously seen while it was in fact not part of the encoding phase, this would constitute a false alarm. Latter type of response behavior has regularly been reported in older adults and is suggested to be a product of an increased reliance on a sense of familiarity rather than more controlled (explicit) memory processes (Edmonds et al., 2012). Differences in reaction times, which are likewise reported on a regular basis (e.g., Grady, Randy McIntosh, Horwitz, & Rapoport, 2000) are assumed to rather be a product of decision making than an indicator of a decrement in sensory and perceptual processing speed (Habak et al., 2008; Pfütze, Sommer, & Schweinberger, 2002).

1.4.2 The impact of stimulus age on face recognition performance

One factor, that has been suggested to account for age related differences in face recognition, is the observation of greater recognition sensitivity with stimuli of a person's own age relative to faces of other ages (Anastasi & Rhodes, 2005; Hills & Lewis, 2011). This effect has been termed own-age bias (OAB) and is considered as a contributor to obtained age differences which has been neglected in the past since the majority of studies presented college-aged targets when assessing age differences and ignored the potential for superior recognition of own-age faces (Anastasi & Rhodes, 2005). The OAB is considered to be predominantly a product of more experience or contact with a person's own age group relative to other age groups (Rhodes & Anastasi, 2012), analogous to the (amongst face recognition researchers) well-known other-race effect (e.g., Hancock & Rhodes, 2008) which describes better recognition of own-race than other race faces. Wiese, Komes, and Schweinberger (2012) recently reported more accurate recognition memory for older over younger faces when the older group had a high degree of daily contact with older relative to younger persons. Furthermore, Ebner and Johnson (2009) found a positive relation ($\beta = .43$) between recognizing older faces and amount of contact with older adults. This association was, however, only observable in younger participants between recognizing older faces and amount of contact with older adults.

2. The present research project

2.1 Overview of dissertation-relevant manuscripts

Paper 1

Obermeyer, S., Kolling, T., Schaich, A., & Knopf, M. (2012). Differences between old and young adults' ability to recognize human faces underlie processing of horizontal information. *Frontiers in Aging Neuroscience*, *4*, 3. https://doi.org/10.3389/fnagi.2012.00003

Paper 2

Schaich, A., Obermeyer, S., Kolling, T., & Knopf, M. (2016). An own-age bias in recognizing faces with horizontal information. *Frontiers in Aging Neuroscience*, 264. https://doi.org/10.3389/fnagi.2016.00264

Paper 3

Schaich, A., Obermeyer, S., Kolling, T., & Knopf, M. (2016). Age differences between younger and older adults in recognizing familiar faces: The impact of horizontal information. *Manuscript under Revision in Journal of Cognitive Psychology*.

2.2 The role of horizontal information in face processing at a higher age

As pointed out above, despite the enormous number of papers on face recognition research, little is known about how faces are being processed. The overwhelming majority of studies trying to answer this very question widely agree that faces are perceived as configurations which is inferred from disrupted recognition due to manipulations such as inversion (FIE). An equally prominent example of the importance of the spatial relations (configural processing) within a face is the Thatcher illusion (Thompson, 1980) which likewise compares differences in perceiving a face that is presented upright and upside-down. By additionally inverting eyes and mouth with respect to the rest of the face, a grotesque face is being produced, which becomes immediately noticeable when the face is upright but hardly apparent when inverted. Though this is a well-known phenomenon in perceptual psychology, to my knowledge there is not a single study that tested for this effect at a higher age. It is rather assumed, that findings from assessing younger adults can be generally accepted, including at a higher age. While my favorite book on faces (Hole & Bourne, 2010) covers the development of face processing from infancy to childhood in two whole chapters, face processing at a higher age gets mentioned in the context of own-group biases on only one page. What I am trying to say is, that, given the fact of an ageing society, there is an obvious need for understanding the impact of age on general and specific cognitive function, especially in a domain as important as face recognition which reflects a crucial ability of socio-psychological functioning. Previous findings on the importance of horizontal information in faces constitute a new and promising approach to understanding why faces may be special stimuli. When planning the current research project, our first thought on the barcode model was, whether its predictions would be likewise applicable at a higher age. Furthermore, how great the impact of filtered stimuli on recognition would be compared to faces that have not been altered (often referred to as "veridical" faces or for the purpose of this dissertation "unfiltered faces") which had not been assessed to that point. There was superior recognition sensitivity of vertical + horizontal information over horizontal information observable in the results by Goffaux and Dakin (2010) which was addressed by the authors, however effect sizes between horizontally filtered stimuli and unfiltered faces remained unknown.

2.2.1 Study 1: Are older adults able to recognize filtered faces similar to younger adults?

An experiment similar to Goffaux and Dakin's study (2010) was conceptualized, however unfiltered faces instead of stimuli that contained both vertical and horizontal information were added, therefore resulting in a 2 (age group) x 2 (orientation: upright vs inverted) x 3 (filter: vertical information, horizontal information, all information) mixed design. Thirty (22 female) younger adults (*M* = 21.07 years, *SD* = 2.83 years) and 30 (22 female) older adults (*M* = 66.20 years, *SD* = 4.75 years) participated in the study[1]. An experimental trial consisted of an encoding phase (1s), a short delay (7s) and a subsequent recall phase, which required participants to decide whether a face had previously been presented in the encoding phase or not. In half of the trials, a target was present (hits) the other half were false alarm trials allowing calculation of target detection sensitivity, one of two dependent variables. As soon as a reaction occurred, response times were recorded providing the second dependent variable. Stimuli were presented with different amounts of target information by applying a morphing technique like the one used on the stimuli of Figure 1. Faces of the recall phase contained between 0% and 100% target information, with 10% increments. The main finding of the study was that younger and older adults' face recognition sensitivity did only differ in one of the 6 experimental conditions, namely when faces were presented upright and only horizontal information was available.

Our publication was the first to show differential effects of horizontal information on younger and older adults and has been cited 18 times up to this point (28.12.2016). It offers a new perspective on information processing therefor adding to the field of face recognition research at a higher age. The usage of 10% morph-level increments did not really provide additional information, as for sensitivity analysis, data of 0%, 10%, and 20% as well as 80%, 90%, and 100% were grouped together "to perform a more robust analysis since accuracy rates for these morph levels were very similar across orientation and filter conditions within the age groups" (Obermeyer, Kolling, Schaich, & Knopf, 2012, p. 4). Although this data transformation was justified as indicated by the absence of aging effects, omitting morph-levels 30% - 70% does

[1] The following information apply to all three studies: Participants were students of Frankfurt Universities. Young adults were undergraduate students of Frankfurt Goethe-University; older adults all attended the University of the third age, a program for education at a higher age. Abovementioned false alarm analyses were conducted as well as basic cognitive function was always formally tested via working memory assessment but are not being reported as neither revealed age differences.

represent a non-economical procedure and was considered in the next studies. Another shortcoming is reflected in not testing for a face inversion effect. As we specifically focused on generating an experimental setup that would allow for comparing the results by Goffaux and Dakin (2010), we chose a relatively short exposure duration interval (1s) and likewise presented both younger and older participants with young (college-aged) faces. Those two factors both represented potential confounds and were addressed in the next study.

2.2.2 Study 2: The impact of exposure duration and stimulus age on face recognition in younger and older adults

The finding that stimulus age impacts face-recognition performance is one of the very sparsely pursued approaches to face recognition research at a higher age. Recent meta-analytic findings quantify differences in sensitivity due to the OAB at a medium effect size of g = 0.37 (analogously interpretable to Cohen's d) in favor of same-age compared with other age-faces (Rhodes & Anastasi, 2012). The second study focused on whether an OAB would be observable in either younger or older adults when presented with horizontally filtered faces. Additionally, a longer exposure duration interval was applied to ensure sufficient stimulus learning resulting in a 2 (age group) x 2 (stimulus age) x 2 (filtered vs unfiltered faces) x 2 (short vs longer exposure) mixed design. By increasing the exposure duration (up to 8s), the previously applied operationalization of face recognition in study 1 would unlikely produce normally distributed sensitivity data but likely result in ceiling effects as the task would become too easy; at least for those trials displaying unfiltered faces. Therefore, stimulus material was standardized more strictly compared to study 1 (elliptical outer forms) and moreover, morph-videos were generated. This involves, on any given trial, an (unfamiliar) starting face that gradually merges into a previously presented target face (hit trial) or a control face (false alarm trial). In case of target absence, no response by the participant was required. This procedure is usually applied with stimulus material that is personally familiar to the participant (which was likewise done in study 3, please see below) and has been used before by different researchers (Herzmann, Schweinberger, Sommer, & Jentzsch, 2004; Keenan et al., 1999; Keenan, Freund, Hamilton, Ganis, & Pascual-Leone, 2000). Consequently, instead of reaction time, the amount of target information necessary for making a decision served as the second dependent variable aside sensitivity. Due to the additional factor (stimulus age) sample sizes increased (compared to study 1) resulting in 47 younger participants (*M* = 21.89 years, *SD* = 3.27 years) and 49 older adults (*M* = 67.78 years, *SD* = 5.35 years). Social contact was measured as the time spent with other persons and as the number of contact persons. Either measure did not differ within the older and younger age group considering the between subjects factor stimulus age.

When analyzing the results, no differences in amount of target information necessary for making a familiar judgement were found between all groups. Therefore, sensitivity remained as the only dependent variable of interest focusing on answering three research questions:

(1) Are older adults able to recognize younger faces with horizontal information when the exposure duration interval is longer?
(2) Is there an OAB observable for either age group?
(3) Is filtered and unfiltered face recognition interrelated?

Latter hypothesis follows the idea that greater association between filtered and unfiltered stimuli would suggest a common underlying factor, whereas little to no correlation would question convergent face-specific processing. First, the results of study 1 were replicated, as older adults were not able to recognize younger faces, not even with long exposure duration. Additionally, study 2 showed that older adults were however able to recognize horizontal information, when presented with faces of their own age (OAB), again only when exposure duration was long. Lastly, there were high correlations between unfiltered and filtered face recognition sensitivity for younger adults but not for older adults. This last finding helps understand the underlying mechanisms which were likely different between younger and older adults. In the paper, we pursue three approaches to explaining the obtained results. First, certain facial features such as ageing cues (e.g., wrinkles) could be especially salient information to individuals who share a common face space, which could be anything that ties an individual to a certain group. Here, it would be a person's age, however, many other constellations of significance exist (e.g., race, gender). This approach directly relates to the two remaining discussion points. We suggest that the obtained correlations in younger adults reflect the ability to process faces configurally. The source of information that remains with configural processing disrupted (in older adults) is analytic processing. Since an exposure duration interval of 8 seconds leaves the observer with plenty of time to scan a visual structure for salient cues, feature-based processing likely took over, concurring with results which reported a switch from configural to analytic processing with increased exposure duration (Hole, 1994). Furthermore, efficiency of analytic processing may be additionally moderated by the initially proposed attenuation of ageing-salient information which might be especially pronounced in older compared to younger adults.

The paper was likewise accepted by *Frontiers in Ageing Neuroscience*. To my knowledge, it is the first study that systematically assessed stimuli of different ages with horizontally filtered information. Especially the obtained correlations between filtered and unfiltered conditions within the younger sample and respective absence within the older group seriously question the applicability of the barcode hypothesis at a higher age.

As always, there are points to improve upon. We did observe different correlations between recognition sensitivity and the contact measures, however no clear pattern emerged, which is somewhat in line with the limited number of papers available. Since the experiment did not actually manipulate type of face processing (configural vs feature-based processing) our findings do not exhaustively allow the conclusion that configural processing is disrupted in older adults when horizontal information is available. Aside suggesting further research on this topic, future studies should add faces that are familiar to the subjects, which was initially applied when publishing the barcode hypothesis (Dakin & Watt, 2009) and is likewise addressed by the following study.

2.2.3 Study 3: The impact of horizontal information on recognizing familiar faces

Lastly, we pursued extending the conclusions that had been presented so far. As pointed out above, theorizing about face recognition in general is problematic, since unfamiliar and familiar face processing seem to be quite different. However, assessing familiar face recognition is likewise problematic for a number of reasons. Importantly, a pool of stimuli has to be tailored to participants individually. When measuring familiar face recognition, mostly famous faces are being used (O'Toole, Wenger, & Townsend, 1998). While on a day-to-day basis, familiarity with an unfamiliar face is established through repeated exposure, encoding modalities are quite different for famous faces. Obviously, most people will not encounter German Chancellor Angela Merkel in person. Developing familiarity with particular celebrity faces will be limited to media like television, internet, and newspapers. On the one hand, representations of celebrities might therefore differ regarding their formation or may even be represented differently due to encoding modalities. On the other, one might argue that familiar face recognition is almost exclusively assessed via images or videos – the same modalities available for encoding famous faces. Carbon (2008) showed that recognition of famous faces might be especially fragile to modifications (such as adding facial hair, or removing beauty patches) suggesting predominant "iconic" processing for famous faces. In contrast, recognition of personally familiar faces was not affected by facial modifications. The author concludes that intense observations and social interactions might constitute facial expertise to a degree unachievable via media alone. This does in fact argue for not using celebrity faces, which we however did in the last study. But the origin of study 3 was based on a different idea as we were wondering how to conceptualize an experiment that would present participants, especially older adults, with stimuli that would be as familiar as possible. This ultimately resulted in using participant's own faces which has been investigated rather sparsely in previous research. Interestingly, like faces relative to objects, a person's own face has been proposed as special. Quantitative differences favoring self-face have been observed by various researchers over both famous (Caharel et al., 2002; Keenan et al., 2000) and personally familiar faces (Keenan et al., 1999; Keyes & Brady, 2010; Tong & Nakayama, 1999). Again, qualitative differences have been suggested: processing one's own face was shown to be associated with predominant left-hemispheric activation (Keenan et al., 1999, 2000), while others stress activation of the right hemisphere (Kircher et al., 2000, 2001) or even bilateral activation (Keyes & Brady, 2010; Taylor et al., 2009). Reviewing pertinent research, Gillihan and Farah (2005) conclude that for self-face recognition, a clear pattern of anatomical localization has yet to emerge. The finding that a person's own face is recognized better than other categories of faces, which is referred to as "self-face advantage", was eventually the reason why we conducted an experiment on self-face recognition. By utilizing famous faces as a condition that would very likely be less familiar to participants we were able to make clear a priori predictions. There were two major differences regarding design and experimental setup compared to study 2: there was no between-subjects factor differentiating stimulus age and no encoding phase was provided. Instead, on any given trial, a starting face (congruent with the participant's gender) gradually morphed into either a target stimulus (famous faces vs the participant's own face) or a control face. Participants were instructed to press one of two buttons (famous vs self-face) analogous to Keenan et al (1999). In case of target absence, no response was required. Prior to the experiment, pretesting procedures assessed individual familiarity with the celebrity faces to ensure similar baseline familiarity with the material. Since either age group was presented with age-matching stimuli, separate analyses were conducted. As introduced above, the approach to analyzing and interpreting the results will follow the idea of quantitative differences and qualitative differences (regarding the underlying face processing mechanisms). Within either age group, quantitative differences were expected regarding:

(1) the factor familiarity: greater self-face recognition performance compared to famous faces (i.e., a self-face advantage)
(2) the filter factor: better performance with unfiltered compared to filtered stimuli

Furthermore, two findings would be indications of differences in face processing mechanisms within either sample:

(1) A familiarity x filter interaction
(2) The absence of associations between filtered and unfiltered recognition, analogous to study 2

For the younger age group (14 females, 9 males, aged between 18 and 36 years (*M* = 22.16 years, *SD* = 4.26 years)), results were as expected and followed a pattern similar to study 2. Sensitivity to unfiltered faces was greater than with filtered stimuli while at the same time unfiltered faces were recognized with less target information compared to stimuli with horizontal information. Furthermore, a self-face advantage was observable with both dependent variables with one comparison showing marginally significant. In other words, the self-face was recognized better and at an earlier morph-level than the celebrity faces, independent from stimuli being filtered or not. Additionally, correlations between amount of target information for filtered and unfiltered stimuli were observable, suggesting similar processing mechanisms. The older age group (13 females, 9 males) aged between 62 and 83 years (*M* = 68.45 years, *SD* = 5.44 years) displayed a completely different behavioral pattern. For sensitivity data, a main effect for familiarity was observable as hypothesized, but only when faces were unfiltered. This pattern was reversed when faces contained horizontal information, which represents a "self-face disadvantage". In fact, sensitivity to filtered self-faces was found to not differ significantly from zero, suggesting older adults were unable to self-recognize. For unfiltered faces, no differences in the amount of target information were obtained. However, older participants made their decision along the morph continuum with significantly less target information, when filtered famous faces had to be recognized compared to their own faces.

In sum, the older group was not able to self-recognize when a self-face image only contained horizontal information. This finding likely stems from different face processing mechanisms with filtered and unfiltered faces since, again, no interrelations between the conditions were observable as opposed to the younger age group. The results of study 3 might be initially the most interesting compared to the other two since self-face recognition is considered as an intriguing field of research, which was likewise expressed verbally by most participants, both younger and older adults. By again generating morph-videos, it was ensured that ceiling effects in performance became more unlikely, which in general depicts a major problem when assessing familiar face recognition. Other than study 2, study 3 did not allow for testing an OAB since the design was not fully crossed (stimulus age). When conceptualizing the experiment, this between-subjects factor was primarily not included, as general familiarity with young celebrity stimulus material seemed unlikely on the part of the older age group. Although stimuli were equalized as best as possible, pictorial differences as well as factors like facial distinctiveness were not held constant. As discussed in the manuscript, testing middle-aged celebrity faces would provide an interesting approach to future research ensuring that participants are exposed to the same pictorial information (though neglecting a potential OAB) and may increase the probability of comparable baseline familiarity. Latter would especially be more easy to achieve by including a smaller number of celebrity faces which should ideally match the number of self-face images from methodological standpoint - yet another point which could be improved upon. Although the likelihood of discovering a self-face advantage may have been increased due to repeatedly presenting the same self-face stimulus (priming effects and image specific processing), it is even more surprising, that older adults were unable to recognize their own filtered faces. In a way, this finding closes the circle on the very question our research group raised back when planning study 3: If provided with the individually most familiar facial material, how would older adults perform? Despite this finding, several questions remain unanswered. The last paragraph will try to integrate the results of all three studies and suggest an approach how to proceed with future research.

2.3 General evaluation, conclusion and future research

Approaching the question what information is extracted from faces as a basis for recognition, our research provides important results concluding that, for older adults, it is not horizontally oriented information as proposed by the barcode model. All results regarding younger adults however, are in line with previous research. Sensitivity to vertical information and horizontal information significantly differed as shown by our first study. Furthermore, effects of familiarity were observable as predicted for both study 2 and 3 (i.e., longer exposure duration as well as presenting participants' own faces was followed by better face recognition performance). Lastly, participants likely processed stimuli configurally as inferred from examining interrelations between recognizing unfiltered and filtered faces. All of these findings however did not show for older adults. Our conclusions of study 2 suggest two major differences: Firstly, analytic processing was being performed with filtered faces, when exposure duration was long and older faces were displayed, and secondly, older adults may be especially efficient in detecting aging cues. With that said, why did older adults fail to recognize filtered self-face material? There are two factors, which might resolve this inconsistency. First, the second study enabled participants to visually scan for ageing cues in an encoding phase, which was not given in study 3, where participants had to rely on memory entries. Secondly, analytic processing of (supposable) salient aging cues (or individuating features in general) suggest, that older adults would have been given the opportunity to e.g., visually scan for specific wrinkles around the eyes, a slightly crooked nose or the like which should ultimately lead to recognition, at least above chance level. It is however suggested, that the abovementioned transfer from configural to analytic processing with unfamiliar faces is not equally expectable with familiar facial stimuli, which require structural codes. In terms of Bruce and Young's (1986) model, a threshold level of activation would have to be reached that would ultimately enable a (specific) FRU resulting in recognizing a familiar face. This process however requires configural processing which, as pointed out above, was likely not enabled in older adults. From the perspectives of a younger and an older participant of study 3 the following might have happened: A trial starts with an unfamiliar filtered face which itself is not recognizable for older adults in two ways: Since it is filtered, they cannot perceive a configuration. Additionally, since the face is unfamiliar, no FRU activation can occur. Although, younger adults were likewise confronted with the latter, they were able to perceive a facial configuration that changed incrementally as the morph video continued. Both, younger and older adults were instructed to show a reaction, as soon as they recognized themselves or a famous face, which can only be achieved by continuously comparing the unfamiliar configuration with the configurations (FRUs) of the own face and the famous faces. For older adults, the more promising strategy to recognizing filtered trials would have been to accept the inability to process the given information and to focus on fine details at least concerning their own faces. This switch however becomes even less likely, since half of the trials were unfiltered which enabled older adults to perceive whole faces and therefor a configural processing strategy was likely to be successful. In study 2 however, when given the opportunity to study unfamiliar facial material, the tendency to rely on memory entries (i.e., structural codes) is not a promising strategy. Here, older (and younger) participants likely found out that there was time to scan the (older) stimuli for salient features which ultimately resulted in usable working memory storage such as ("wrinkles around the left eye").

Goffaux, Poncin, and Schiltz (2015) recently published a paper arguing for the age-invariant applicability of the barcode hypothesis (contrary to the findings of our workgroup). Assessing participants aged from 6 to 74 years of age, the authors however report performance dropping notably with a non-linear function best fitting performance as a function of age (which basically means that reaction times decreased at a higher age). Though the authors did not report accuracy as a dependent variable, a supplementary table reveals performance for the oldest age group (59 - 74 years) of M = 87% correct responses (SD = 2.80) for faces that were presented upside down with only vertical information available. In the text, the authors mention that "since the task was specifically designed to achieve good performance levels, accuracy was close to ceiling in several conditions and age groups" (p. 6). Critically, it should be noted, that the task had participants match faces with both target and match present at the same time with stimuli being identical (i.e., the match was not mirror-reversed, or another image of the same face was used). This type of task likely confounded face recognition with simple picture matching and represents the type of practical failure in the field (Burton & Jenkins, 2011) I was referring to above. I would like to ask the reader of this dissertation to go back to Figure 1. Please try to picture an image of your own face was being filtered in the same fashion. Our last study basically says, that the information in images 1d-1f lead to recognition accuracy in older persons at an accuracy level of 0. Goffaux et al. (2015) report accuracy matching unfamiliar images that contain information similar to images 1g-1i (however turned upside-down!) ranges around 90%. While the most familiar face (own face) becomes unrecognizable in one study, another reports ceiling effects with least familiar faces, i.e., unfamiliar younger faces, displayed in an especially demanding condition (upside down and filtered vertically). There is something strange in the neighborhood! I am covering this in depth because it reflects the completely unmanageable amount of methods and measurement paradigms that are and have been applied in the well over 100.000 publications on face recognition mentioned above combined with the vast overlapping of theoretical concepts which however are generalized and subsumed under the concept of face processing.

This dissertation contributes to contemporary face recognition research by assessing a recent theory from a developmental perspective. Studies 1 and 2 concurrently (with different methodological approaches being applied supporting convergent validity) show that compared with younger participants, older adults' face recognition performance with filtered younger faces is impaired suggesting fundamentally different processing mechanisms. It is proposed, that older adults are unable to apply configural processing, the main source of information when it comes to recognizing faces and are therefore left with feature-based processing. The latter in turn seems to be a promising strategy when it comes to recognizing older filtered faces which contain more salient cues compared to younger faces. Configural processing is primarily inferred from clear associative patterns between filtered and unfiltered recognition in younger adults but not in older adults. However, whether the obtained correlations in younger adults are in fact a product of a common underlying (face-specific) construct or in part derive from the applied method cannot be differentiated in the studies. Still, it is proposed that differences in older adults' performance reflect variability in recognizing degraded visual material, rather than variability in face recognition. Or in a more striking conclusion: older adults do not perceive faces when looking at stimuli with horizontal information.

Our research marks a starting point to a range of possible research questions which should be subject to systematic assessment in future studies. One of the questions involves, whether older adults do have the same amount of information available when making a familiar or unfamiliar decision which would point towards differences on a perceptual level. Less efficiently functioning V1 neurons responsible for horizontally aligned structure would provide a relatively simple explanation. Since vertical recognition sensitivity did however not differ between age groups, this approach seems somewhat implausible. However, systematically manipulating faces and other objects with orientation filters could exclude the hypothesis of general inefficiency restricted to the horizontal information band in older adults. Critically, a systematic variation of stimulus age with both familiar and unfamiliar material, ideally crossed with different methodological approaches needs to be carried out. An isolated research question, which could be investigated with comparably little effort would be the hypothesized analytic processing strategies in older adults that might compensate for inaccessible configural processing, which itself needs to be examined.

3. Zusammenfassung

Menschliche Gesichter scheinen in Abgrenzung zu anderen visuellen Stimuli etwas Besonders zu sein. Der Nachweis hierzu wird bei Gesichtererkennungsexperimenten vor allem mittels Beurteilungsgütemessungen erbracht, d.h., quantitative Überlegenheit gegenüber Nicht-Gesichtern (Objekten). Darüber hinaus hat sich gezeigt, dass Gesichter insbesondere aufgrund ihrer (individuellen) Konfigurationen verarbeitet werden - anders als Objekte, deren Informationsverarbeitung vor allem merkmalsbezogen erfolgt (Hole & Bourne, 2010). Untersuchungen hierzu reichen bis in die späten sechziger Jahre des vorigen Jahrhunderts zurück, als erstmals gezeigt wurde, dass Gesichtererkennung disproportional durch Inversion beeinträchtigt wird (Wegfall konfiguraler Informationsverarbeitung), ein Effekt, welcher noch heute zum Nachweis konfiguraler Verarbeitungsmechanismen herangezogen wird und als „Face Inversion Effect, FIE" bezeichnet wird (Yin, 1969). Interessanterweise wird Objekterkennung hingegen durch Inversion nur minimal beeinflusst, da, anders als bei Gesichtern, (merkmalsbezogene) Verarbeitungsmechanismen weitestgehend intakt bleiben. Die "Barcode-Hypothese" (Dakin & Watt, 2009) beschreibt die Wichtigkeit von horizontal angeordneten visuellen Informationen in menschlichen Gesichtern in Abgrenzung zu Informationen anderer Orientierung. Im Gegenzug scheinen vertikale Informationen besonders wenige identitätsstiftende Merkmale zu transportieren und darüber hinaus nicht konfiguralen Verarbeitungsmechanismen zu unterliegen, was unter anderem mittels des FIE untersucht wurde (Goffaux & Dakin, 2010). Das Modell von Dakin und Watt (2009) war mit Beginn des vorliegenden Forschungsvorhabens noch nicht aus einer entwicklungspsychologischen Perspektive untersucht worden. Ziel der vorliegenden Dissertation war es, die Wichtigkeit horizontaler visueller Informationen im höheren Alter zu beleuchten. Trotz Unmengen publizierter Arbeiten zum Thema Gesichtererkennung wurde diese wichtige Fähigkeit bisher nur wenig bei älteren Erwachsenen erforscht und eine umfassende Theorie zur Gesichterverarbeitung wurde für das höhere Alter noch nicht hervorgebracht. Es besteht jedoch weitestgehend Konsens darüber, dass ältere Erwachsene gleichermaßen Gesichter aufgrund ihrer Konfigurationen verarbeiten (Meinhardt-Injac, Persike, & Meinhardt, 2014b), hierbei jedoch weniger effizient sind, was sich vor allem in höheren Reaktionszeiten sowie verminderter Beurteilungsgüte niederschlägt (Grady et al., 2000). Letzteres wird jedoch als Produkt des Entscheidungsprozesses im experimentellen Setting angesehen und nicht als ein Dekrement sensorisch-perzeptueller Geschwindigkeit (Habak et al., 2008). Vor allem in den letzten Jahren wurden vermehrt Publikationen zum sog. „own-age bias, OAB" hervorgebracht, ein sozio-psychologisches Phänomen, welches die überlegene Erkennung von Gesichtern eigenen Alters gegenüber solchen anderer Altersklassen beschreibt (Anastasi & Rhodes, 2005) und hiermit eine Faktor hervorbringt, welcher in den allermeisten altersvergleichenden Studien der Vergangenheit keine Berücksichtigung fand, da fast ausschließlich Stimulusmaterial Anwendung fand, welches Gesichter jüngerer Erwachsener abbildet.

In der vorliegenden Dissertation wurde die Wichtigkeit horizontaler Informationen im Altersvergleich anhand dreier Studien überprüft. In Studie 1 untersuchten wir eine jüngere (M = 21,07 Jahre, SD = 2,83 Jahre) und eine ältere Gruppe (M = 66,20 Jahre, SD = 4,75 Jahre) in einem 2 (Altersgruppe) x 2 (Orientierungsfaktor: aufrecht vs. invertiert) x 2 (Filterungsfaktor: vertikale Filterung, horizontale Filterung, keine Filterung) gemischten Design. Die Aufgabe der Teilnehmer bestand darin, zuvor kurz enkodierte (1sek) einzelne Gesichter nach einer Verzögerungsphase (7sek) wiederzuerkennen, wobei zur Hälfte Zielgesichter, zur anderen Hälfte zwecks Kontrolle von Antworttendenzen andere „falsche Alarmgesichter" dargeboten wurden. Der wichtigste Befund bestand darin, dass nur in einer von 6 experimentellen Bedingungen Altersunterschiede aufgezeigt werden konnten, nämlich, wenn es sich um aufrecht dargebotene Gesichter mit horizontalen Informationen handelte, welcher sich gleichermaßen im Titel des publizierten Artikels wiederfindet (Obermeyer et al., 2012).

Der oben erwähnte OAB stellte die zentrale Fragestellung der sich anschließenden zweiten Studie dar, welcher als potentieller Einflussfaktor in der vorherigen Studie nicht berücksichtigt wurde, da ausschließlich jüngere Gesichter dargeboten worden waren. Zusätzlich erweiterten wir das Design um den Faktor Enkodierdauer, da das vorherig applizierte Lernintervall möglicherweise für ältere Erwachsene zu gering gewesen sein könnte. Studie 2 untersuchte somit 47 jüngere (M = 21,89 Jahre, SD = 3,27 Jahre) und 49 ältere Teilnehmer (M = 67,78 Jahre, SD = 5,35 Jahre) in einem 2 (Altersgruppe) x 2 (Stimulusalter) x 2 (Filterungsfaktor: horizontale Filterung, keine Filterung) x 2 (Enkodierdauer: 0,8sek vs. 8sek) gemischten Design. Anders als in der vorherigen Studie wurden den Probanden, vor allem zwecks Vermeidung von Deckeneffekten, Morphsequenzen von unbekannten Gesichtern dargeboten, welche sich in der Abrufphase - analog zu Studie 1 - graduell entweder in ein zuvor gelerntes Zielgesicht oder ein wiederum unbekanntes „falsches Alarmgesichte" entwickelten. Als zusätzliche Analysen wurden Interrelationen zwischen Bedingungen gefilterter und ungefilterter Darbietung berechnet, welche Hinweise auf kongruente Informationsverarbeitungsmechanismen liefern sollten. Zum einen konnte der Befund von (Obermeyer et al., 2012) repliziert werden, da die ältere Gruppe deutlich geringere Beurteilungsgütemaße aufwies als die jüngere Gruppe, wenn es sich um jüngere Gesichter handelte, die kurz dargeboten worden waren. Darüber hinaus konnte gezeigt werden, dass die ältere Gruppe ähnlich gute Leistungen vollbrachte, wenn alterskongruente Stimuli wiederzuerkennen waren, allerdings nur dann, wenn das Enkodierungsintervall lang war. Zusätzlich konnten bedeutsame Korrelationen zwischen den Sensitivitätsmaßen für gefilterte und ungefilterte Stimuli aufseiten der jüngeren Gruppe verzeichnet werden, vor allem dann, wenn ebenso alterskongruente Gesichter erkannt werden sollten. Für die ältere Gruppe konnten interessanterweise keinerlei signifikanten Interrelationen zwischen gefilterter und ungefilterter Darbietungsweise verzeichnet werden, was die Vermutung nahelegt, dass diesem Ergebnis divergierende Verarbeitungsmechanismen zugrunde liegen könnten. Die altersinvariante Leistung hinsichtlich gefilterter älterer Gesichter unter verlängerten Enkodierbedingungen wird in der Diskussion des Artikels (Schaich, Obermeyer, Kolling, & Knopf, 2016) mit einem potentiellen Umschalten von konfiguralen Erkennungsmechanismen hin zu analytischen Prozessen (Hole, 1994) in Zusammenhang gebracht, welcher bei älteren Erwachsenen möglicherweise besonders stark ausgeprägt sein könnte. Dies könnte zum einen eine schiere Notwendigkeit darstellen, aufgrund der nicht vorhandenen Fähigkeit gefilterte Stimuli überhaupt konfigural verarbeiten zu können. Für letzteres spräche vor allem das Nicht-Erkennen von jungem Stimulusmaterial unabhängig von der Enkodierdauer. Zum anderen stellt die besondere Salienz von Altersmerkmalen einen plausiblen Erklärungsansatz dar, welche bei älteren Personen stärker ausgeprägt sein könnte als bei Jüngeren.

In der letzten Studie wurde, anderes als in den beiden vorangegangen, den Teilnehmern bekanntes Stimulusmaterial dargeboten. In der Forschung zur Gesichtererkennung ist die Unterscheidung zwischen unbekannten Gesichtern, welche Probanden erstmalig präsentiert werden einerseits und bekannten Stimuli (z.B. Schauspieler oder Politiker) andererseits, ein Faktor, der oftmals vernachlässigt wird. Dies lässt sich so verstehen, dass z.B. neu vorgebrachte, gesichts-spezifische Wahrnehmungsphänomene oftmals nur anhand entweder unbekannter Stimuli oder unter Darbietung ausschließlich bekannten Materials erprobt und publiziert werden. Jedoch weisen eine Reihe von Studienergebnissen darauf hin, dass unbekannte und bekannte Gesichtererkennung qualitativ unterschiedlich zu sein scheinen. Vor allem gut belegt sind quantitative Unterschiede zwischen den beiden Kategorien, die sich in Form von erhöhten Reaktionszeiten und geringerer Beurteilungsgüte bei Verwendung von unbekanntem gegenüber bekanntem Stimulusmaterial manifestieren (Campanella, Hanoteau, Seron, Joassin, & Bruyer, 2003). Qualitative Unterschiede werden unter anderem hinsichtlich der Wichtigkeit internaler, z.B. Augen, Nase (bei bekannten Gesichtern wichtiger) und externaler Merkmale (Haare, Ohren) zwischen den beiden Kategorien hervorgebracht (Ellis, Shepherd, & Davies, 1979). Darüber hinaus fanden neurophysiologische Untersuchungen unterschiedliche neuronale Verarbeitungspfade (Natu & O'Toole, 2011) sowie stärkere interhemisphärische Integration bei bekannten, jedoch nicht bei unbekannten Gesichtern (Mohr, Landgrebe, & Schweinberger, 2002). Studie 3 prüfte den Einfluss von horizontalen Informationen auf die Erkennungsleistung bekannter Gesichter unter Verwendung alterskongruenter berühmter Gesichter sowie das eigene Gesichts. Letzteres geschah unter der Prämisse, dass ein Stimulus präsentiert werden sollte, der den Probanden maximal bekannt sein würde. Ähnlich, wie bei der Unterscheidung bekannter und unbekannter Stimuli, konnten bei Untersuchungen zur Eigengesichtserkennung quantitative sowie qualitative Unterschiede aufgezeigt werden. So wurde von besserer Beurteilungsgüte hinsichtlich des eigenen Gesichts im Vergleich zu sowohl berühmten (Caharel et al., 2002; Keenan et al., 2000), als auch persönlich bekannten Gesichtern berichtet (Keenan et al., 1999; Keyes & Brady, 2010), welche, ebenso wie bei der Unterscheidung von unbekannten und bekannten Gesichtern (Eigengesicht ausgenommen) auf qualitativ unterschiedliche Prozesse zurückführbar sein könnten. Auch hier werden unter anderem divergierende hemisphärische Aktivierungsmuster diskutiert, wobei eine klare anatomische Lokalisation bisher aussteht (Gillihan & Farah, 2005). Die überlegene Erkennung des eigenen Gesichts im Vergleich zu Gesichtern anderer Kategorien wird als „self-face advantage" bezeichnet und stellte die zentralste Überlegung für die letzte Untersuchung dar. Ziel war es, die Barcode-Hypothese mittels eines Stimulus zu überprüfen, der den Probanden maximal bekannt sein sollte.

In Studie 3 wurden 23 jüngere (14 Frauen) im Alter von 18 bis 36 Jahren (*M* = 22,16 Jahre, *SD* = 4,26 Jahre) und 22 ältere Teilnehmer (13 Frauen) im Alter zwischen 62 und 83 Jahren (*M* = 68,45 Jahre, *SD* = 5,44 Jahre) in einem 2 (Altersgruppe) x 2 (Filterungsfaktor: horizontale Filterung, keine Filterung) x 2 (Bekanntheit: berühmte Gesichter, eigenes Gesicht) gemischten Design untersucht. Im Vergleich zur vorherigen Studie bestanden die entscheidenden Unterschiede darin, dass sowohl der Zwischengruppenfaktor Stimulusalter sowie eine vor der Abrufphase appliziertes Enkodierungsintervall entfielen. Gleichermaßen wurde davon ausgegangen, dass mögliche Assoziationen zwischen Messungen ungefilterter und gefilterter Erkennung auf die Verwendung konvergierender Verarbeitungsmechanismen hinweisen würden. Während die Ergebnisse der jüngeren Gruppe hypothesenkonform sich im Auffinden präferierter Erkennung des eigenen Gesichts in sowohl gefilterter als auch ungefilterter Form auszeichnete, zeigte sich für die ältere Gruppe ein völlig gegensätzliches Verhaltensmuster bezüglich der Erkennung horizontaler Informationen. Während das ungefilterte Eigengesicht noch bedeutsam besser im Vergleich zu den ungefilterten berühmten Gesichtern erkannt wurde, fiel das Sensitivitätsmaß für gefilterte Selbsterkennung bis auf 0 ab. Darüber hinaus konnte gezeigt werden, dass, anders als die jüngere Gruppe, die älteren Teilnehmer signifikant mehr Zielgesichtsinformationen benötigten, wenn es sich um das eigene Gesicht mit horizontaler Information handelte. Wie in Studie 2, konnten auch in Studie 3 bedeutsame Korrelationen zwischen ungefilterter und gefilterter Erkennung auf Seiten der jüngeren Gruppe verbucht werden, jedoch waren keinerlei Assoziationen für die ältere Gruppe zu verzeichnen. Analog zu Studie 2 wird dieser Befund als Hinweis für divergierende Verarbeitungsmechanismen bei älteren Erwachsenen bezüglich gefilterter und ungefilterter Gesichtererkennung betrachtet.

Zusammenfassend lässt sich aus einer, die drei Studien integrierenden Perspektive, konstatieren, dass ältere Erwachsene zwar fähig sind, Gesichtsstimuli mit horizontalen Informationen zu erkennen, dies allerdings nur unter bestimmten Bedingungen. Zum einen war dies dann der Fall, wenn die dargebotenen Stimuli der eigenen Altersklasse entsprachen. Zum anderen, wenn es sich um ein langes Enkodierungsintervall handelte. Hierbei wurden allerdings wahrscheinlich nicht vornehmlich die den unbekannten älteren Gesichtern zugrundeliegenden Konfigurationen verarbeitet und in der Abrufphase erinnert, sondern vielmehr wird eine Enkodierungsstrategie mit Fokus auf alterssaliente Merkmale vermutet.

Obwohl die zum jetzigen Zeitpunkt vorhandene Datenlage nicht abschließend ausreicht, konfigurale Erkennungsmechanismen bei älteren Erwachsenen zu verneinen, ergibt sich vor allem im direkten Vergleich zu den jüngeren Studienteilnehmern ein auffällig abweichendes Effektmuster. Bei allen drei Studien bestätigen sich sämtliche a priori formulierten Hypothesen sowohl bezüglich der gefundenen quantitativen als auch dem Nichtvorhandensein qualitativer Unterschiede in Zusammenhang mit jüngeren Probanden. Ersteres bezieht sich auf die Faktoren Inversion in Studie 1, Enkodierdauer in Studie 2 und Vertrautheit in Studie 3. Hinsichtlich all jener Faktoren zeigten sich quantitative Unterschiede in Richtung der Erwartung. Vor allem aber auf beiden Stufen des jeweilig vorhanden Faktors Filterung - oder mit anderen Worten: die gleichen Effekte gelten für sowohl ungefilterte Gesichter als auch solche, die nur horizontale Informationen enthalten. Darüber hinaus zeigen sich in Studie 2 und 3 teilweise beträchtliche Zusammenhänge zwischen gefilterter und ungefilterter Gesichtererkennung. Somit lassen sich die bereits bestehenden Publikationen von Dakin und Watt (2009) sowie Goffaux und Dakin (2010) widerspruchfrei mit den hier dargestellten Befunden in Einklang bringen - allerdings nur für jüngere Erwachsene.

Der Stellenwert der vorliegenden Forschungsarbeit liegt vor allem darin, dass durch die erstmalige Überprüfung des Barcode-Modells im Altersvergleich durch Obermeyer et al. (2012)

ein Faktor zu einem bis dato spärlich erforschten Bereich hinzutritt. Die Unterschiedlichkeit der Reaktionsmuster auf Gesichter mit horizontaler Information bei älteren Erwachsenen im Vergleich zu jüngeren Erwachsenen zieht sich wie ein roter Faden durch die drei hier vorgestellten Studien und gewinnt einerseits an Robustheit aufgrund der Unterschiedlichkeit der Forschungsansätze (z.B. bekannte vs. unbekannte Gesichter). Jedoch aufgrund der Gesichterforschung inhärenten Konstrukt- und Methodenvielfalt andrerseits können die hier dargelegten Befunde nur einen Startpunkt für weitere notwendige Fragestellungen bieten. Allem voran gilt es, einen spezifischeren Nachweis der unterstellten Unterschiedlichkeit der Verarbeitungsmechanismen zu erbringen, idealerweise unter Integration der Faktoren Stimulusalter sowie die konzeptuelle Unterscheidung beziehungsweise Quantifizierung von Wahrnehmungsprozessen auf der einen Seite und Gedächtniseffekten auf der anderen.

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Differences between old and young adults' ability to recognize human faces underlie processing of horizontal information

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Recent psychophysical research supports the notion that horizontal information of a face is primarily important for facial identity processes. Even though this has been demonstrated to be valid for young adults, the concept of horizontal information as primary informative source has not yet been applied to older adults' ability to correctly identify faces. In the current paper, the role different filtering methods might play in an identity processing task is examined for young and old adults, both taken from student populations. Contrary to most findings in the field of developmental face perception, only a near-significant age effect is apparent in upright and un-manipulated presentation of stimuli, whereas a bigger difference between age groups can be observed for a condition which removes all but horizontal information of a face. It is concluded that a critical feature of human face perception, the preferential processing of horizontal information, is less efficient past the age of 60 and is involved in recognition processes that undergo age-related decline usually found in the literature.

Keywords: face perception, age differences, memory, spatial frequencies

INTRODUCTION

Humans rely heavily on the sense of vision, and there is perhaps no stimulus of greater social importance than a face. It is easy to understand its evolutionary significance if the influences faces have on behavior, such as face symmetry on attractiveness or others' degree of resemblance to one's kin on willingness to help others, are regarded as vital characteristics for mate selection, altruistic behavior, and other routine social interactions (Alvergne et al., 2007; Bressan and Zucchi, 2009). Predicting other people's intentions or behavior is one such important social interaction that is mediated by face processing (Baron-Cohen, 1994, 1995).

This kind of visual processing has been demonstrated to be susceptible to an aging brain: older adults (OA) are found to exhibit lower sensitivity scores than younger adults (YA; Grady et al., 2000; Firestone et al., 2007) as well as higher latencies (Maylor and Valentine, 1992). The former seems to occur mainly because of higher false alarm rates (Bartlett et al., 1989; Fulton and Bartlett, 1991; Edmonds et al., 2012) and the latter appears to be due to decision-making, not sensory, or perceptual processing impairments (Pfütze et al., 2002). Taking into account these specific differences, research studying developmental trajectories indicate two key adult development phases which show a decreased ability for face perception: the first one has been noted to occur around the age of 50, and the second – more noticeable – one is believed to take place between 60 and 80 years of age (Crook and Larrabee, 1992; Chaby and Narme, 2009). Since face perception and its importance to memory processes is a key cognitive component that ensures adequate functioning at a higher age, effort is being put into finding possible reasons for this apparent age-related decline by the fields of memory, cognition, and human lifespan development.

Since many vital behaviors hinge on face recognition, young, and old humans must form an identity for each individual; they must transfer identities to memory, link them with other information such as name or personality traits, as well as retrieve this kind of information at any given time. For a face to be recognized by its observer, the most widely known – and perhaps most complex – perceptual network, the visual system, has to carry out a number of intricate processes.

The human visual system is a complex array of cells with the retina, lateral geniculate nucleus, and visual cortex being its main perceptive components (with the prefrontal cortex arguably being the first integrative cognitive component). Even at the level of the retina, different neurons are highly specialized for detecting orientation of lines, edges, color, movement, shape, and contrast (among others) and convey this information to the lateral geniculate nucleus. This structure in turn receives reciprocal innervations from cortical layers and acts as a relay station that directs visual information to the occipital lobe. The lion's share of visual processing is consequently done by the visual cortex and its association cortices, which ultimately results in the separation of two streams (a ventral "what" stream integrating recognition, categorization, and identification as well as a dorsal "where" stream, which mainly handles spatial attention of visual information) that converge at the level of higher cortical processing (Mishkin and Ungerleider, 1982). In order to simulate how the visual system operates while initially breaking down a stimulus, image filtering is done to imitate the first stages of human visual perception, as displayed in various computational models in visual- and neuropsychological research (Watt, 1994; Watt and Dakin, 2010).

Specifically, breaking down (and thereby filtering) an image into its spatial frequencies is of special importance, as it has been linked to face perception (Dakin and Watt, 2009; Goffaux and Dakin, 2010). Filtering images spatially results in exclusion of certain spatial frequencies; image information is restricted by the kind of filter that is applied. If for example an orientation pass-filter of 90° is applied to an image, all spatial frequencies are filtered in a way so that information primarily aligned at a 90° angle will pass, thus filtering an image horizontally (a small amount of frequencies aligned at other angles are filtered as well, due to the application of a wrapped Gaussian profile; for further information see Dakin and Watt, 2009; Goffaux and Dakin, 2010). These filtered images serve as stimuli that are used to test the influence of such spatial frequencies on early visual processes in human vision. Since psychophysical data show higher recognition sensitivity for horizontally filtered stimuli (as opposed to vertical ones), the notion of a "biological bar code" in the human visual system that drives human face perception by preferential processing of horizontal spatial frequencies has been put forth (Dakin and Watt, 2009). When the visual system has to operate on limited and degraded information during the presentation of orientation-discriminate (filtered) stimuli, the "bar code" describes the likelihood of horizontally filtered faces to be recognized. Horizontal spatial frequencies are an informative source for face identification and a good approximate for an image that contains all information, mainly due to the alignment of prominent features such as eyes, mouth, nose, as well as brow and chin regions.

Other, more global, influential theories concerning age-related cognitive decline have described internal processing stages as mediating factors between sensory and motor processes, where peripheral sensory processes may not be affected at all (Cerella, 1985). These stages have been further linked to theories of cognitive decline with increasing age, such as theories attempting to explain apparent age differences in terms of either a decrease of efficiency in localized frontal lobe structures (West, 1996, 2000) or a decrease in less localized network-based connections (Greenwood and Parasuraman, 2010; Zanto et al., 2011). Furthermore, age-related decreases in various cognitive tasks, including face perception, have been attributed to a more synchronous and lateralized brain in OA, whereas in comparison YA show more localized activity in each hemisphere (Cabeza, 2002).

In order to attribute decreases cognitive functioning to specific structures or processes, the method of stimulus presentation and its influence on response behavior, especially in OA, must be considered. There is still an ongoing debate whether encoding or retrieval difficulties for OA are responsible for an age-related decline in declarative memory. This debate is rooted in arguments for retrieval impairment due to an increasing lack of internal organization with age (Craik and Lockhart, 1972; Burke and Light, 1981) and arguments for encoding impairment due to increasing lack of encoding strategies with age (Sanders et al., 1980; Craik and Byrd, 1982). More specifically, studies measuring regional cerebral blood flow in episodic memory tasks including face perception have shown that YA encode information using the left prefrontal cortex and retrieve information using its right counterpart, the right prefrontal cortex (Cabeza et al., 1997; Grady, 1998). OA do not exhibit the same pattern: very little regional cerebral blood flow during encoding can be seen over the entire prefrontal cortex and only slightly more can be observed during retrieval. However, OA show heightened regional cerebral blood flow in other areas as compared to YA, such as the thalamus and hippocampus. This pattern suggests that the prefrontal cortex carries out complex visual analysis in YA, but OA's brains involve more scattered areas of activation, possibly to compensate for organization difficulties (Grady et al., 1998). Additionally, during presentation of degraded stimuli, OA and YA alike shift activation from visual association cortices to the prefrontal cortex during encoding (possibly for a greater need of complex visual analysis), even though OA spread the shift of activation over other areas as well, giving rise to the idea that a more localized activity (as in YA) translates to superior response behavior (Grady et al., 1994). The importance of the prefrontal cortex during encoding seems apparent by its clear activation pattern in YA; OA show – at least physiologically – greater deficits during encoding, which in turn raises the question if confronting OA with manipulated stimuli during the encoding phase in face perception tasks is methodologically sound (the face-inversion effect is a popular choice at this point, where encoding and target stimuli are traditionally orientation-congruent; Grady et al., 2000).

There are various theories that attempt to explain age differences. More global theories fare well when explaining an overall set of abilities that diminish with age, but are susceptible to complex interactions of individual abilities that may or may not undergo age-related decline and may or may not have an impact on other abilities. An approach that focuses on perception of specific aspects of a face (its spatial frequencies) might in fact help to explain an age-related decline in face perception in a sense that it is a focused approach to a single perceptual ability that has been shown to undergo age-related decline. It has been demonstrated (for YA) that horizontally filtered images carry more information of a face than vertically filtered images, and it is therefore supposed that neurons in the visual cortex can decode information more meaningful, which leads to the statement that preferential processing of horizontal frequencies is necessary for the ability of face processing (Goffaux and Dakin, 2010).

From a developmental standpoint, it remains to be seen if the same holds true for OA and if a possible deficit in such preferential processing might shed light on age-related decline in face perception. In this experiment, OA with a comparatively high cognitively and perceptually challenging social background are compared to young university students under relatively realistic learning situations, where an un-manipulated and upright face had to be encoded and compared to faces of various orientation and filter conditions during recall.

MATERIALS AND METHODS

PARTICIPANTS

Thirty (22 female) young participants ($M = 21.07$ years, $SD = 2.83$ years) and 30 (21 female) old participants ($M = 66.2$ years, $SD = 4.75$ years) were assessed in this study. Age of male and female participants did not significantly differ in either young or old age group [$t(28) = 0.51$, $p = 0.615$; $t(28) = 0.85$, $p = 0.402$, respectively]. All participants were right-handed and had normal or corrected-to-normal vision. All young participants were undergraduate students of Frankfurt's Goethe-University; all old participants were enrolled in the university's U3L ("University of the third age") program for education at a higher age.

PROCEDURE

Subjects took a computerized motor reaction time test and two short paper-and-pencil tests. The paper-and-pencil tests consisted of a (digit-span) subtest of the WAIS-R (Wechsler Adult Intelligence Scale, Tewes, 1994) for working memory assessment and the FAIR (Frankfurt Attention Inventory, Moosbrugger and Oehlschlägel, 1996) for attention assessment. After a short break, subjects took part in the face recognition experiment. For all tests, dummy-trials were used to familiarize the subject with specifics of the test. Overall, the session lasted for about 90 min. Informed consent was obtained from all subjects. The Experiment was conducted in accordance with the ethical guidelines of the German Psychological Society and is also in line with the Ethical Principles of Psychologists and Code of Conduct of the American Psychological Association. This research was conducted in the absence of any commercial or financial relationships.

FACE RECOGNITION EXPERIMENT

The psychophysical experiment was presented by E-Prime (E-Prime 2.0, psychology Software Tools, Inc., Sharpsburg, PA, USA). Subjects sat at a distance of roughly 60 cm from the screen. It consisted of 132 trials which served to measure latency and sensitivity of the subjects' responses. Each trial commenced after a 3000 ms "get-ready" signal, which took the form of a dot (2° visual angle) that changed in color from red to yellow to green, with each colored dot being presented for 1 s apiece. No subject reported difficulties identifying different colors. Subsequently, the stimulus of the learning phase was shown for 1000 ms while subjects were instructed to remember the face of this part of the trial, as it would have to be compared to a face in the testing phase. The latter appeared after 7000 ms, where a fixation cross was shown in the center of the screen for 5000 ms and became enlarged twice in the last 2000 ms in order to prepare the subject for the beginning of the testing phase (2°, 4°, and 6° visual angle, respectively). During the testing phase, subjects were instructed to respond as quickly and as accurately as possible to the question "*does this face appear familiar in comparison to the face just learned?*" (**Figure 1**). Subjects were thus forced to give a yes-or-no answer, and accordingly pressed different keys on the keyboard. These keys were assigned in a way that half of the subjects pressed the "x" key to a positive ("yes") and the "m" key to a negative ("no") response, whereas the other half had the opposite assignment, as to eliminate the possibility of a bias toward eliciting a positive response with the left hand, and a negative response with the right hand, or vice versa. There were no differences in sensitivity or latency for the different assignments within the young and old age group [for sensitivity: $t(28) = 0.84$, $p = 0.406$; $t(28) = 0.74$, $p = 0.462$, respectively and for latency: $t(28) = 0.34$, $p = 0.735$; $t(28) = 0.27$, $p = 0.786$, respectively].

STIMULI

Stimuli in the learning phase were presented in an upright, unfiltered manner, to maximize potential learning of the stimulus. The target image in the testing phase could either be upright or inverted, as well as filtered (exclusion of horizontal or vertical spatial frequencies) or unfiltered. In addition to orientation and filter levels, the test-stimulus could take one of 11 different morph levels – 0–100% learning phase stimulus content (LSC) with 10% increments. This was done to introduce ambiguity and to avoid a learning process to either accept or reject the stimulus based on a completely different or entirely identical appearance. Stimuli in the experiment showed young, Caucasian, and male or female human faces with neutral expressions (with hair and ears were completely removed). Stimuli did not exhibit beards or other distinctive features such as jewelry, scars, or alike. Stimuli that did not meet these criteria were excluded based on the judgment of four

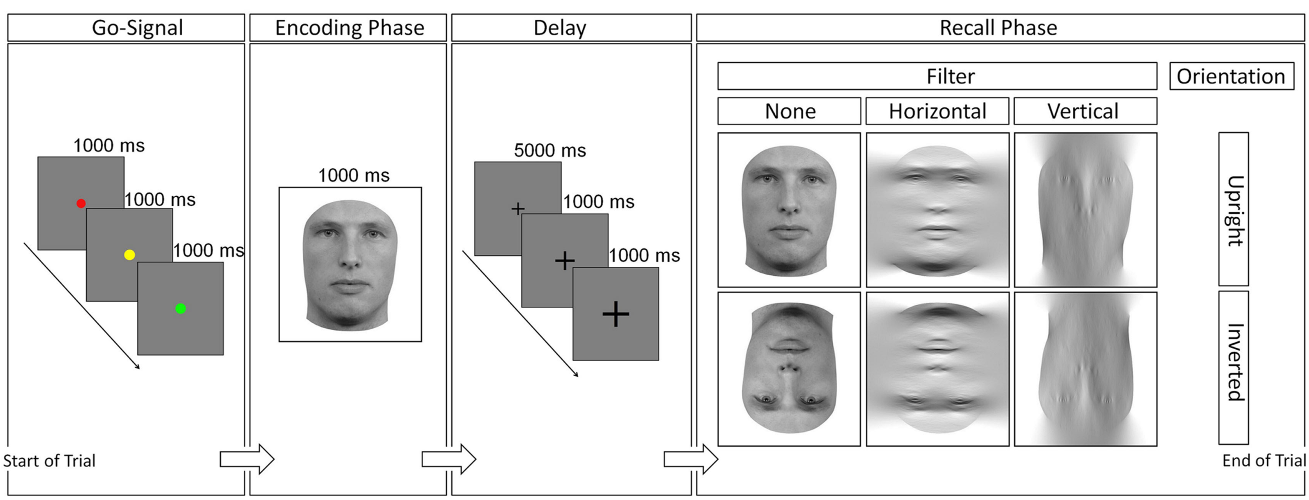

FIGURE 1 | Procedure of a trial. The go-signal was followed by the encoding phase, a fixation cross accompanying a short delay, and finally the recall-phase. Response was given at the last stage and served as measures for sensitivity and latency measurements. One stimulus of the combination upright/inverted (orientation), and unfiltered/horizontally/vertically (filter) was presented in the recall-phase.

individual raters. Images were normalized and gray-scaled to HSV color space. Stimuli were presented on a 38 by 30 (width by height) cm monitor, with a resolution of 1280 × 1024 pixels. Stimuli varied slightly from 522 to 690 pixels in height ($M = 607.18$, $SD = 39.45$) to preserve the individual aspect ratio, but always had a width of 400 pixels (or at an approximate viewing distance of 60 cm, 11.3, and 16.9° of visual angle in width and height, respectively). Stimuli were provided by a face databases as well as colleagues (Langner et al., 2010; special thanks to R. C. L. Lindsay and Queen's University Legal Studies Lab Members). Morpheus Photo Morpher 3.16 (Morpheus Software LLC, Santa Barbara, CA, USA) and Gimp 2.6 (The Gimp Team, www.gimp.org) were used to crop and edit the stimuli; filtering was done by Matlab 7.13 (The Mathworks, Inc., Natick, MA, USA). The matlab-code was provided by its developer (for details of the filtering method see Dakin and Watt, 2009; Goffaux and Dakin, 2010; special thanks to S. C. Dakin).

MOTOR REACTION ASSESSMENT

The motor reaction time assessment consisted of a psychophysical test, also programmed in E-Prime, in which subjects simply pressed a key on the keyboard once the stimulus, a black dot (2° visual angle) on a gray background, appeared. Subjects completed the test with each hand separately (2 × 60 trials), pressing the same two keys they later did in the face recognition experiment. Each subject's motor reaction time mean was assessed for each hand and subsequently subtracted from the appropriate hand in the face recognition experiment in order to obtain individual cognitive latencies as clean as possible. This is especially important since motor reaction times between the age groups differed [$t(58) = 3.81$, $p = 0.003$].

COVARIATES

Subjects completed the FAIR attention test, which involves the test taker to highlight as many correct stimuli (geometric figures) as possible in a given amount of time (2 × 3 min). They also took the WAIS-R digit-span subtest that required subjects to remember a steadily growing chain of numbers that was read aloud by the experimenter and repeated by the subjects in the same order as they were announced, as well in the reverse order (during a subsequent second test).

RESULTS

DATA ANALYSIS

For sensitivity, latency, Hit/False Alarm Rates, 2 (age group) × 2 (orientation) × 3 (filter) mixed-model repeated-measures ANOVAs were used to analyze the results. The "age group" factor is the only between-subjects factor that compares means of YA and OA, whereas the other factors describe within-subjects factors. The "orientation" factor compares means of upright faces versus inverted faces, and the "filter" factor describes the comparison of unfiltered versus horizontally filtered versus vertically filtered stimuli. SPSS 19 (IBM Corporation, Armonk, NY, USA) was used for all analyses.

REMOVAL OF OUTLIERS

Prior to descriptive statistical analysis, outliers were removed: simple motor reaction time data points were excluded had the subject pressed the key before the stimulus appeared on the screen, or if s/he took less than 100 ms or more than 400 ms to respond. Individual outliers of the remaining data points were treated by means of inter-quartile range (IQR) outlier exclusion [values below (mean-1.5*first IQR) as well as above (mean + 1.5*third IQR), Hoaglin et al., 1983; Tukey, 1977]. In the end, a mean of motor reaction time for each subject's hand was created so that this latency could be subtracted from the corresponding hand yielding the latency in the face recognition experiment. For face recognition reaction time data, lenient low and high cut-offs as well as an IQR exclusion were applied (low cut-off below 500 ms; high cut-off above 4000 ms). After outlier exclusion, 4.54% of data points from the young age group and 9.42% from the old age group were not available for statistical analysis, which is an acceptable amount of data loss (Ratcliff, 1993). For trials that had latency outliers, matching sensitivity measures were also excluded. For the dependent variable sensitivity, a d'-analysis was carried out, which included 80–100% LSC-stimuli and 0–20% LSC-stimuli grouped in Hit/Miss and Correct Rejection/False Alarm categories, respectively. Morph levels spanning the upper and lower 20% of either end of the morph-degree spectrum were grouped together to perform a more robust analysis, since accuracy rates for these morph levels were very similar across orientation and filter conditions within the age groups [YA: $F(2,29) = 0.89$, $p = 0.416$; OA: $F(2,29) = 0.42$, $p = 0.662$]. In addition to a d'-analysis, a Hit/False Alarm rate analysis as well as a Reaction Time analysis were carried out on the same data set.

COVARIATES

Standardized scores (according to age category) were obtained from raw score measurements. For the FAIR, an independent t-test yielded a non-significant comparison [$M_{YA} = 6.87$, $SD_{YA} = 1.76$, $M_{OA} = 6.17$, $SD_{OA} = 1.72$, $t(58) = 1.56$, $p = 0.125$], as well as a significant WAIS-R comparison, favoring OA [$M_{YA} = 10.37$, $SD_{YA} = 2.63$, $M_{OA} = 11.83$, $SD_{OA} = 1.95$, $t(58) = 2.45$, $p = 0.017$].

FACE RECOGNITION: SENSITIVITY

A descriptive d'-analysis as a function of age and stimulus type can be seen in **Figure 2**. An analysis of variance with the dependent variable Sensitivity (d') revealed a significant age group main effect [$M_{YA} = 1.69$, $SD_{YA} = 0.74$, $M_{OA} = 1.32$, $SD_{OA} = 0.52$, $F(1,58) = 5.1$, $p = 0.028$], a significant orientation main effect [$M_{Upright} = 2.11$, $SD_{Upright} = 1.66$, $M_{Inverted} = 0.9$, $SD_{Inverted} = 1.46$, $F(1,58) = 142.91$, $p < 0.001$], a significant filter main effect [$M_{Unfiltered} = 2.9$, $SD_{Unfiltered} = 1.35$, $M_{Horizontal} = 1.16$, $SD_{Horizontal} = 1.53$, $M_{Vertical} = 0.45$, $SD_{Vertical} = 1.05$, $F(2,57) = 172.34$, $p < 0.001$], and a significant filter with age group interaction [$F(1,58) = 4.32$, $p = 0.015$]. An independent t-test further classified the only significant comparison as d'-values of upright horizontally filtered stimuli: $M_{YA} = 2.42$, $SD_{YA} = 1.56$, $M_{OA} = 1.47$, $SD_{OA} = 1.41$, $t(58) = 2.33$, $p = 0.023$, Cohen's $d = 0.69$. Furthermore, comparisons of horizontal and vertical conditions for each orientation within each age group were significant for YA but not for OA (YA, upright orientation: $M_{Horizontal} = 2.42$, $SD_{Horizontal} = 1.56$, $M_{Vertical} = 0.86$, $SD_{Vertical} = 1.14$, $t(29) = 5.52$, $p < 0.001$; YA, inverted orientation: $M_{Horizontal} = 0.54$, $SD_{Horizontal} = 0.93$, $M_{Vertical} = -0.06$,

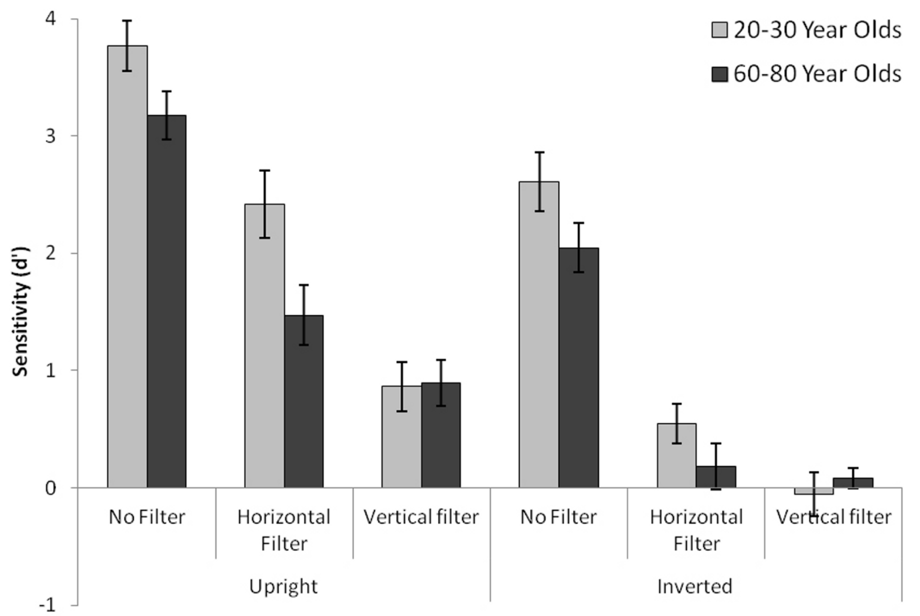

FIGURE 2 | Sensitivity scores for both age groups across different filter and orientation conditions.

$SD_{Vertical} = 2.33$, $t(29) = 2.38$, $p = 0.027$; OA, upright orientation: $M_{Horizontal} = 1.52$, $SD_{Horizontal} = 1.41$, $M_{Vertical} = 0.9$, $SD_{Vertical} = 1.07$, $t(29) = 1.98$, $p = 0.057$; OA, inverted orientation: $M_{Horizontal} = 0.18$, $SD_{Horizontal} = 1.07$, $M_{Vertical} = 0.08$, $SD_{Vertical} = 0.46$, $t(29) = 0.44$, $p = 0.666$].

FACE RECOGNITION: LATENCY

Mean reaction times as a function of age and stimulus type can be seen in **Figure 3**. The analysis of variance with the dependent variable Reaction Time (milliseconds) revealed a significant age group main effect [$M_{YA} = 908.14$, $SD_{YA} = 416.13$, $M_{OA} = 1534.6$, $SD_{OA} = 568.65$, $F(1,58) = 34.49$, $p < 0.001$], a significant orientation main effect [$M_{Upright} = 1168.84$, $SD_{Upright} = 553.81$, $M_{Inverted} = 1273.9$, $SD_{Inverted} = 617.73$, $F(1,58) = 12.72$, $p = 0.001$], a significant filter main effect [$M_{Unfiltered} = 1183.71$, $SD_{Unfiltered} = 608.99$, $M_{Horizontal} = 1298.88$, $SD_{Horizontal} = 587.04$, $M_{Vertical} = 1175.59$, $SD_{Vertical} = 564.89$, $F(2,57) = 4.66$, $p = 0.011$], as well as a significant filter with age group interaction [$F(2,57) = 9.64$, $p < 0.001$], a significant orientation with filter interaction [$F(2,57) = 8.84$, $p < 0.001$].

FACE RECOGNITION: HIT/FALSE ALARM RATES

Hit rates as well as false alarm rates (given in percent of total answers) are shown in **Figures 4A,B** as a function of age and stimulus type. Further analyses of variance similar to the sensitivity-ANOVA were carried out in order to test not just for an overall sensitivity difference, but to also test for hit rate and false alarm rate differences between the groups separately. The false alarm rate ANOVA yielded no significant age group difference, $M_{YA} = 25.61\%$, $SD_{YA} = 25.22\%$, $M_{OA} = 23.67\%$, $SD_{OA} = 26.8\%$, $F(1,58) = 0.27$, $p = 0.606$. Conversely, the hit rate ANOVA instead yielded a significant age group difference, $M_{YA} = 65.8\%$, $SD_{YA} = 31.5\%$, $M_{OA} = 54.17\%$, $SD_{OA} = 36.74\%$, $F(1,58) = 8.49$, $p = 0.005$, with the only significant age group comparisons being both inverted filter conditions. For inverted horizontally filtered stimuli: $M_{YA} = 55.88\%$, $SD_{YA} = 25.4\%$, $M_{OA} = 33.18\%$, $SD_{OA} = 32.99\%$, $t(58) = 2.99$, $p = 0.004$, Cohen's $d = 1.25$. For inverted vertically filtered stimuli: $M_{YA} = 34.74\%$, $SD_{YA} = 26.82\%$, $M_{OA} = 16.77\%$, $SD_{OA} = 25.18\%$, $t(58) = 2.68$, $p = 0.01$, Cohen's $d = 0.95$.

DISCUSSION

The ability to recognize a face has been attributed to the specific arrangement of horizontal information that a face possesses. Indeed, subjects in this experiment had lower sensitivity scores when confronted with a vertically filtered stimulus as opposed to a horizontally or unfiltered one.

This was found to be true for both upright and inverted orientation conditions: learned image information can be retrieved relatively accurately when the target stimulus does not differ from the encoding stimulus, less accurately when horizontal spatial frequency processing had to be used exclusively to extrapolate the target stimulus's identity from encoded information and least accurately when the stimulus contained only vertical spatial frequencies. This pattern was found for both age groups alike, albeit statistical differences within each age group concerning the various filter levels differ.

Whereas young participants showed clear-cut, significant, decreases for each filter level in its respective orientation, older participants only showed significantly higher d'-values for unfiltered stimuli. In other words, horizontally and vertically filtered stimuli did not affect older subjects' ability to recognize a learned identity significantly, regardless of orientation. Older subjects do

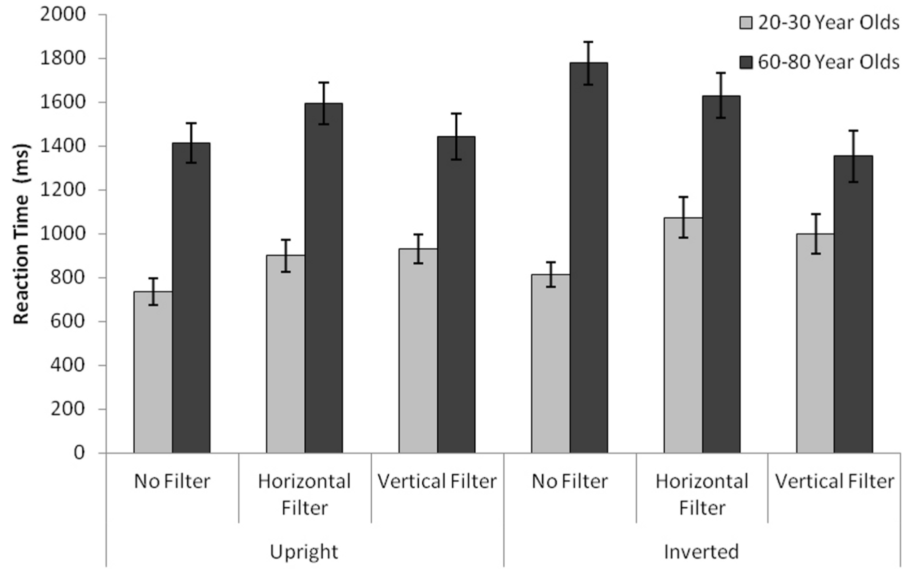

FIGURE 3 | Time it took for young and old subjects to respond to stimuli of different conditions. "Cognitive" latencies are depicted; each subject's individual motor reaction time was subtracted from the total latency.

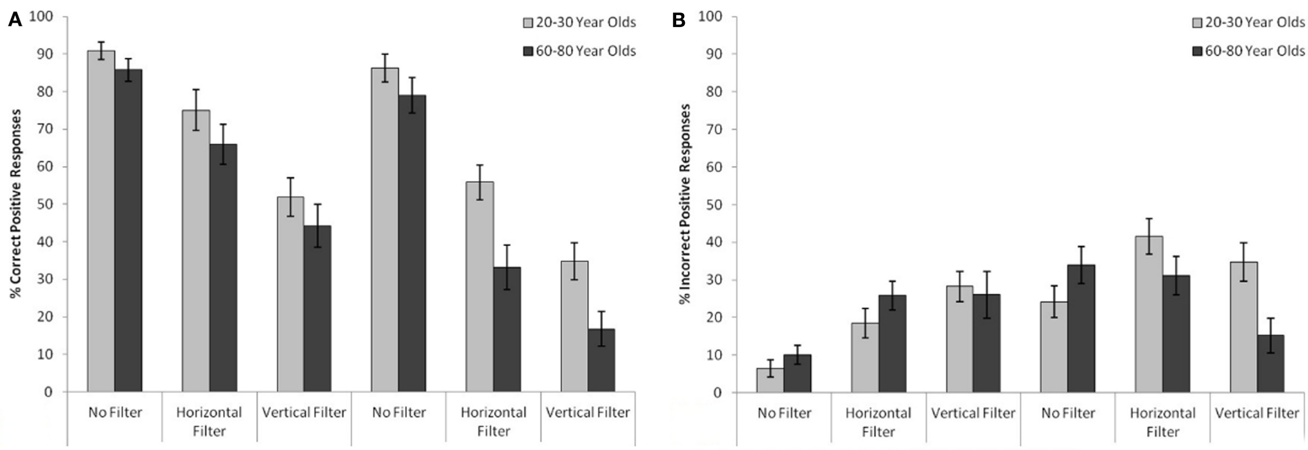

FIGURE 4 | (A) Hit rates. Amount of correct "yes" responses for both age groups for different stimulus types **(B)** false alarm rates. Amount of incorrect "yes" responses for both age groups for different stimulus types.

not recognize horizontally filtered faces better than vertically filtered stimuli – at least statistically – even though a trend toward significance does exist for this comparison. However, taking into account the evenly distinguishable decreasing recognition sensitivity with different filter methods in YA, greater differences of OA in this regard suggest that older subjects are not as able to make use of horizontal spatial frequency processing as younger subjects are. Furthermore, a bigger age effect for all informative recall-stimuli conditions could have possibly been found had the subject pool been extended to older university students as well as regular older individuals; this is certainly a topic for further research.

The noticeable difference of horizontal (as compared to vertical) conditions that was only observed in young adults also results in a difference between the two age groups, as sensitivity scores in vertically filtered conditions were nearly identical among young and old adults: young and old subjects clearly differed for the judgment of upright horizontally filtered stimuli. Thus, as this being the only statistically significant condition across age groups, the hypothesis that processing of horizontal spatial frequencies undergoes age-related decline is strengthened.

Older participants did perform worse on this recognition task for all relevant stimuli (if vertically filtered stimuli are excluded as informative source), but the means separating the two age groups apart differ enough to generate a statistical difference only in the condition which offers the preferential processing of horizontal spatial frequencies as a useful recognition tool. If the purpose of such filtering methods is to simulate how the visual system operates during early stages of stimulus break-down (in this case mainly break-down due to edge detection of spatial frequencies), given the finding that OA are seemingly less efficient at a condition which requires the use of preferential processing of horizontal spatial frequencies, it seems feasible that a general disadvantage of OA can be generalized and attributed to this relative lack of ability. At the same time, however, the less obvious difference for the unfiltered upright condition, albeit statistically near-significant, might be interpreted to be due to some adaptation mechanism that takes place at an older age, where the filtering of spatial frequencies does not play as big of a role as it does to YA.

There are reasons why older subjects performed relatively equal to young subjects. Expertise for identifying faces is acquired through repeated contact with individuals, where learning new faces, identifying, and remembering them are important tasks with social consequences. An influential model, the in-group/out-group model of face recognition (Sporer, 2001, see also Levin, 1996), proposes that in-group faces are automatically processed due to underlying perceptual expertise, whereas out-group faces are merely categorized as not belonging to the same group than its observer. Further, the model states that there is a strong possibility that this out-group coding does not extend beyond initial labeling as being different thereby limiting the motivation to develop expertise for out-group faces. At the same time, subjects have been noted to perform better on stimuli depicting faces closer to their own age, which might be linked to the time that is spent with individuals of their own age. This finding has been confirmed for young and old age groups and has been subsequently coined the own age bias (Anastasi and Rhodes, 2005; Perfect and Moon, 2005). Recent visual experience with other-age groups, especially with previously unknown individuals (such as other university students as opposed to own young family members whose configural information has been consolidated over years), has been theorized to change the behavior of an individual, in this case the ability to discriminate identities of young faces. Based on these findings it appears plausible that a more cognitive stimulating environment (compared to OA that do not attend university at a higher age) affects cognitive abilities in a positive way: unlike most studies researching age differences, the present older age group was a select group of older university students, which leads to increased "face time" older subjects had interacting with young university students, thereby familiarizing OA with the configuration of young faces.

This study confronted subjects with stimuli exclusively depicting young faces. It is entirely possible that these near-significant differences disappear if older faces are tested as well. Despite antithetic findings concerning the OAB, findings indicate a stronger bias for OA than for YA that hinges strongly on the target stimulus's perceived age (Freund et al., 2011). A goal of future research thus is to investigate whether horizontal spatial frequency processing is intact for the identification of older faces or remains impaired. A third age group, subjects in their mid-thirties, could be of significant interest as well, as it was recently stated that face recognition reaches its peak later than previously thought (Germine et al., 2011). It would be interesting to see how these subjects perform for age groups below and above their own age as postulated higher perceptual abilities go along with expertise of face configurations of older and younger individuals alike (i.e., individuals in their mid-thirties increasingly spend more time with representatives of both age groups).

The present findings indicate that, although it is not entirely evident that OA and YA perform equally in un-manipulated conditions, OA perform less accurately when it comes to identifying faces using the preferential processing of horizontal spatial frequencies. In fact, the greatest difference in sensitivity performance is observed for this horizontal filter condition.

Reaction times between the age groups interact with sensitivity measures in a more clear-cut way. Latencies show that OA need more time to make a judgment about the identity of a face. These differences are present for each condition that was tested, indicating that latency measurements are independent of information content that has to be processed for these age groups. This raises the question what components are responsible for this consistent finding. Since motor reaction times were accounted for by subtracting them individually from the latency during the face recognition experiment, motor reactivity can be excluded as a factor. There is no way to tell from the present data whether sensory perception was slower for OA, or whether it was indeed decision-making that led to a heightened reaction time. Interestingly, however, YA appear to have a higher tendency to respond with "yes" answers during ambiguous or non-informative conditions (inverted filtered conditions), which in general take more time to make, as more parts of the target face have to be compared to the stored encoded information to ensure resemblance. Alternatively, a "no" response can be given as soon as differences are found while matching the target image with the learned stimulus from memory (Lockhead, 1972). If YA exhibit a higher percentage of decisions requiring more decision-making time, higher latencies of OA suggest that indeed sensory processes are slower in OA, which stands contrary to research that states sensory processes remain relatively intact and decision-making drives higher latencies (Pfütze et al., 2002).

Future research in this field could flourish if such a select group of subjects are studied more closely. Psychophysical evidence of this experiment hints at high performing OA being relatively spared when it comes to identifying unknown faces. This is accompanied by better working memory performance and sensitivity scores that fail to reach significance. At this time it is pure speculation, but this select group of older individuals might indeed possess a different physiology than other people of their own age. This could be of substantial relevance given Cabeza's HAROLD model (Cabeza, 2002), Grady's plasticity theory (Grady, 1998; Grady et al., 1998), and Gazzaley's account of impaired attention processes (Gazzaley et al., 2005, 2008) and its involvement of face processing. Perhaps these OA show a smaller degree of compensatory mechanisms, namely less bilateral brain activation and a more localized blood flow to prefrontal cortices.

What stands to debate is also the notion that encoding processes are responsible for a difference in performance between age groups: when encoding and recall conditions were the same, the difference between the groups was not statistically significant and much less apparent as compared to a scenario in which subjects had to use horizontal processing to gather information of identity and compare it to a learned identity. This is supported by previous research that determined memory load during encoding as the factor on which accurate face recognition hinges (Lamont et al., 2005). Encoding of horizontally filtered stimuli would clearly not increase the memory load, but still pose a challenge for older individuals, as impaired cognitive processes (such as the abstraction of a horizontally filtered to an unfiltered face) might already impact the encoding processes (which, as theorized might also be a factor for impaired face recognition).

Another supporting fact for this notion is that what normally seems to be a crucial difference between younger and older age groups, a higher false alarm rate in OA. This finding cannot be supported in this study, since those scores did not differ in conditions where an informed judgment could be made (i.e., unfiltered or horizontally filtered stimuli), but in conditions in which guessing would most likely contribute to the overall low sensitivity scores. This could be explained by a general tendency for OA to respond with a "no," whereas YA respond to ambiguous scenarios more often with a "yes." The same is present for hit rates, whereas OA did not show a different response behavior except perhaps the least informative, inverted vertically filtered, condition, where OA showed less positive responses, thus having a lower hit rate. These findings are both consistent and further explain the overall relatively evenly distributed response behaviors.

Gathering information from a horizontally filtered stimulus and comparing it to stored information appears to be more challenging for OA than for YA, despite OA's general comparable performance, foremost given the disadvantage they were exposed to with young-faced stimuli. Thus, a difference between YA and OA concerning general face recognition ability can be further explained if preferential processing of horizontal spatial frequencies is considered to be a major prerequisite for this ability.

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An Own-Age Bias in Recognizing Faces with Horizontal Information

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Horizontal information, as a result of a selective filtering process, is essential in younger adults' (YA) ability to recognize human faces. Obermeyer et al. (2012) recently reported impaired recognition of faces with horizontal information in older adults (OA) suggesting age-variant processing. Two yet unconsidered factors (stimulus age and exposure duration) that may have influenced previous results, were investigated in this study. Forty-seven YA (18–35 years) and 49 OA (62–83 years) were tested in a 2 × 2 × 2 × 2 mixed design with the between-subjects factors age group (YA vs. OA) and stimulus age (young faces vs. older faces) and the within-subjects factors filter [filtered (HF) faces vs. unfiltered faces (UF)] and exposure duration (0.8 s vs. 8 s). Subjects were presented morph videos between pairs of faces: a starting face gradually merged into either the previously encoded target face or a control face. As expected, results showed an increase in recognition sensitivity (d') with longer exposure duration in YA with both younger and older HF faces. OA, however, were unable to recognize filtered young faces not even with increased exposure duration. Furthermore, only elderly participants showed more accurate recognition with faces of their own age relative to other-age faces (own-age bias, OAB). For YA no OAB was observed. Filtered face recognition was significantly correlated with unfiltered recognition in YA but not in OA. It is concluded, that processing of horizontal information changes at a higher age. Presenting filtered or unfiltered faces both targets convergent face-specific processing only in YA but not in OA.

Keywords: face recognition, own-age bias, exposure duration, horizontal information, spatial frequencies

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INTRODUCTION

While crystallized intellectual abilities and expertise-based knowledge can be preserved until a high age (e.g., Salthouse, 1990) declining cognitive functions with age have been documented especially for working memory, attentional and executive processes (Salthouse, 1996; Craik and Salthouse, 2000; Grady and Craik, 2000). Analogous results have been gathered regarding the ability to recognize human faces (Crook and Larrabee, 1992; Searcy et al., 1999). Despite the age independent necessity to perceive, process and remember human faces on a daily basis this ability seems to develop disadvantageously over lifetime. The majority of studies depict age-dependent decline in facial recognition accuracy (Grady, 2002; Hildebrandt et al., 2013), and slower recognition processing times in OA (Grady et al., 2000). Differences in speed are assumed to rather be a product of decision making than sensory and perceptual processing speed (Pfütze et al., 2002; Habak et al., 2008). Moreover, inflated false alarm rates in OA have regularly been reported (Edmonds et al., 2012; Lee et al., 2014).

One explanation for declining face recognition performance in OA might be face specific processing mechanisms that decrease with age. Other than non-face stimuli, faces are processed primarily according to the configural information contained within them (Hole and Bourne, 2010) which can for example be demonstrated by turning a face stimulus upside-down. Yin (1969) was the first to show that face recognition is disproportionally affected by inversion: the difference in recognition accuracy with upright and inverted stimuli was much greater for faces compared with other types of objects (Face Inversion Effect, FIE). Subsequent research has shown that inversion leaves feature-based (analytic) processing relatively intact but heavily affects configural processing. This key feature in face recognition has extensively been investigated. Interestingly, OA' ability to recognize complex stimuli like objects or scenes (analytic processing) seems to be less affected compared to recognizing faces (Park et al., 1983; Craik and Jennings, 1992; Meinhardt-Injac et al., 2014). The observed age-related decline in face recognition can, however, neither be attributed to reduced capabilities of configural face processing (Diamond and Carey, 1986; Farah et al., 1998; Meinhardt-Injac et al., 2014; Richler and Gauthier, 2014) nor to general-cognitive ability (Hildebrandt et al., 2011). Taken together, research indicates that the processing mechanisms involved in face recognition seem to be preserved with increasing age but become less efficient.

Although an aging-specific face recognition theory cannot be established to this point a number of factors have been suggested to account for differences in facial recognition between age groups. Such factors include an own-age bias (OAB) in face recognition as well as age differences in processing of horizontally aligned facial information. The OAB is characterized by preferential processing of own-age faces relative to faces of other ages (Anastasi and Rhodes, 2005; Hills and Lewis, 2011). Recent meta-analytic findings quantify differences in sensitivity due to the OAB at an effect size of $g = 0.37$ (medium effect; analogously interpretable to Cohen's d) in favor of same-age compared with other age-faces (Rhodes and Anastasi, 2012). A majority of studies conducted in the past presented college-aged targets when assessing age differences and ignored the potential for superior recognition of own-age faces (Anastasi and Rhodes, 2005). The predominant account for own-age superiority in face recognition tasks has been more extensive experience or contact with a person's own age group relative to other age groups (Rhodes and Anastasi, 2012). Corresponding empirical evidence was provided recently by Wiese et al. (2012) who reported more accurate recognition memory for older over younger faces when the OA had a high degree of daily contact with older relative to younger persons. Although only few studies are available, Rhodes and Anastasi (2012) conclude that the amount of contact measured via questionnaires appears to be related to face recognition of other ages. Ebner and Johnson (2009) for example found a positive relation ($\beta = 0.43$) between recognizing older faces and amount of contact with older adults (OA) in younger participants but no significant association recognizing younger faces and contact for OA.

A methodological approach focusing on perceptual processes in facial recognition recently proposed that the specific structure of human faces is what makes them special visual stimuli. Dakin and Watt (2009) applied a filtering process that selectively removes all visual information of an image but those restricted to certain orientation ranges and thereby simulating what information would be passed by V1 neurons (Hubel and Wiesel, 1968) tuned to a specific visual structure. The authors showed quantitative superiority in face recognition sensitivity with horizontal facial information over other alignments. Moving from horizontal to vertical, sensitivity continuously declines reaching lowest performance at vertical alignments. Moreover, those horizontal contours tend to fall into vertically aligned clusters – a phenomenon that was solely observable for faces but not for objects or natural scenes (Dakin and Watt, 2009). This clustering of horizontal visual information along a vertical axis in human faces was labeled biological 'bar code' and is proposed as a highly constrained one-dimensional code that makes faces special visual stimuli. Follow-up studies conducted by Goffaux and Dakin (2010) reported face specific effects for horizontal but not for vertical information as indicated by different face-specific phenomena like the FIE demonstrating that face stimuli that only contain horizontal information are processed configurally.

While Dakin and Watt (2009) measured identification accuracy of celebrity faces, Goffaux and Dakin (2010) assessed recognition performance of unfamiliar faces as indicated by target detection sensitivity (d'). Adding a developmental perspective, Obermeyer et al. (2012) assessed a group of younger ($M = 21.07$ years) and OAs ($M = 66.20$ years). Subjects were presented with either horizontally, vertically or unfiltered facial stimuli presented as either upright or inverted. Both age groups showed similar performance (d') across five experimental conditions but considerably differed in recognizing upright faces that only contained horizontal information (YA > OA). The authors suggest that processing horizontal information may be less efficient in OA.

The present study was conducted to extend the research reported by Obermeyer et al. (2012). First, only young faces were presented to both age groups. Secondly, exposure duration to target faces was held constant at 1 s per trial. The encoding phase may have been too short for OA. The goal of this study is to assess whether OA are able to recognize horizontally filtered faces when they are provided with faces of their own age and are more familiar with the stimulus material presented. Higher accuracy with unfamiliar faces can be achieved by increasing the exposure duration to the stimulus material (Reynolds and Pezdek, 1992; Memon et al., 2003). In our study, a short encoding interval and a long encoding interval are chosen for inducing different levels of visual expertise with the stimulus material. Analogous to Obermeyer et al. (2012), face memory will be assessed presenting unfiltered faces in an encoding phase for unfamiliar faces followed by a recall phase either displaying filtered or unfiltered faces. Since faces with horizontal information are proposed to represent natural faces in a degraded form, it is being investigated whether recognizing filtered faces is associated with unfiltered face recognition for either age group. We take greater correlations between filtered and unfiltered face recognition sensitivity as evidence for underlying convergent face-specific processing.

MATERIALS AND METHODS

Design

A mixed design was used with the between-subjects factors age group (YA vs. OA) and stimulus age (young faces vs. older faces). Filter (filtered vs. unfiltered faces) and exposure duration (0.8 s and 8 s) were both within-subject factors. Target detection sensitivity [(d' = Z(hit rate) – Z(false alarm rate)] was the dependent variable (see e.g., Macmillan and Creelman, 2005).

Subjects

A total of 47 YA ($M = 21.89$ years, $SD = 3.27$ years) participated in the study. While 23 YA (14 female) aged between 18 and 36 years ($M = 22.16$ years, $SD = 4.26$ years) were exposed to young face stimuli, 24 young subjects (14 female) aged between 19 and 26 years ($M = 21.46$ years, $SD = 1.53$ years) were presented with older faces.

Forty-nine OAs ($M = 67.78$ years, $SD = 5.35$ years) took part in the study. Twenty-seven OA (18 female) aged between 60 and 79 years ($M = 67.22$ years, $SD = 5.32$ years) were presented with young faces. Twenty-two OA (13 female) aged between 62 and 83 years ($M = 68.45$ years, $SD = 5.44$ years) were exposed to older face stimuli.

A 2 (stimulus age) × 2 (age group) between-subjects ANOVA comparing participants' mean age confirmed an expected main effect for age group [$F(1,92) = 2512.117$, $MSE = 192166.498$, $p < 0.001$, $\eta_p^2 = 0.965$] but no differences in stimulus age [$F(1,92) = 0.035$, $MSE = 0.701$, $p = 0.852$] and no stimulus age × age group interaction [$F(1,92) = 1.345$, $MSE = 26.856$, $p = 0.249$]. Hence YA exposed to younger faces and YA exposed to older faces as well as OA presented with younger faces and OA presented with older faces were of the same age within each age group. All participants were students of Frankfurt Universities: young adults were undergraduate students of Frankfurt Goethe-University; OAs all attended the University of the Third Age, a program for education at a higher age. All participants were of Caucasian heritage and had normal or corrected-to-normal vision. Experiments were approved by the faculty ethics committee and were in line with APA guidelines according to the ethical principles of psychologists and code of conduct. Written informed consent was obtained from all participants.

Materials

Two experiments were conceptualized: one version displayed young faces as stimuli, and another presented older faces (see **Figure 1**). Experiments were programmed using E-Prime 2.0 (Psychology Software Tools, Inc., Sharpsburg, PA, USA) and presented on a 22″ computer screen (LG 2210PM; resolution: 1680 × 1050) at a viewing distance of approximately 60 cm. The stimulus pool of unfamiliar faces was obtained using different databases (Minear and Park, 2004; Lindenberger et al., 2007; Langner et al., 2010). For all editing work Gimp 2.8 (The Gimp Team[1]) was used. Elliptical outer forms were cropped and converted to grayscale. The width of faces was kept constant at 400 pixels although height consistency varied slightly. Stimuli were mounted on a white 800 × 600 pixels background. Differences in contrast and luminance were equalized as best as possible and conspicuous marks, facial hair, and scars were removed.

Experiments were comprised of 64 trials (32 trials presenting unfiltered faces and 32 trials with filtered faces). In half of the trials a target was present (hits) the other half were false-alarm trials. A hit-trial was comprised of two faces: an unfamiliar face that served as a target face and a starting face that gradually merged into the target face. A false alarm trial was comprised of a third face as the starting face merged into a different face than the target face. From the entire set of faces, stimuli were assigned randomly to serve as starting faces, target faces or non-target faces. Starting faces changed on each trial. Morph continua (videos) were created using Morpheus Photo Morpher v3.16 Industrial (Morpheus Software LLC, Santa Barbara, CA, USA) with a duration of 20 s (for analogous assessment see e.g., Keenan et al., 2000; Kircher et al., 2001). The frame rate was set to 15 images per second creating a "movie-like" character. The morphing process included marking identity salient features of two faces by setting dots to similar areas (e.g., eye region: pupil, iris, lids, eye brow). The number of dots necessary for morphing two faces ranged approximately between 120 and 180 dots per morph template. As reaction times are being recorded by the computational software during experimental procedure, for data analysis, individual mean morph levels for particular conditions were converted from milliseconds to percentages with greater numbers indicating more target information along the morph continuum. Stimuli displaying only horizontally aligned information were generated using Matlab 7.13 (The Mathworks, Inc., Natick, MA, USA). The filtering process includes breaking down a stimulus to its basic components by Fourier transforming it and multiplying the Fourier energy with an orientation filter (wrapped Gaussian profile with a standard deviation of 20°) allowing only horizontal information to pass (for further details see Dakin and Watt, 2009).

To screen for cognitive function, subjects completed the WAIS-R Digit-Span subtest (Tewes, 1991/1994). The WAIS-R Digit-Span subtest involves remembering growing chains of numbers forward and backward and assesses working memory. Participants answered questions related to degree of social contact with younger (18–30 years) and OAs (60–80 years) analogous to Wiese et al. (2012). Subjects were asked to indicate the amount of time they spend with each age group (hours per week) as well as the number of different contact persons. The questions were preceded by a short explanation asking subjects to only consider people they are familiar with.

Procedure

The experiment took approximately 30 min and could be aborted by the subject at any time. All participants completed the experiment. Trials were presented randomly – **Figure 2** displays an experimental target trial. Subjects were instructed to press the space bar with their dominant hand of a standard keyboard as soon as they recognized a target but to show no reaction in case of target absence for each session. No feedback was given.

[1] www.gimp.org

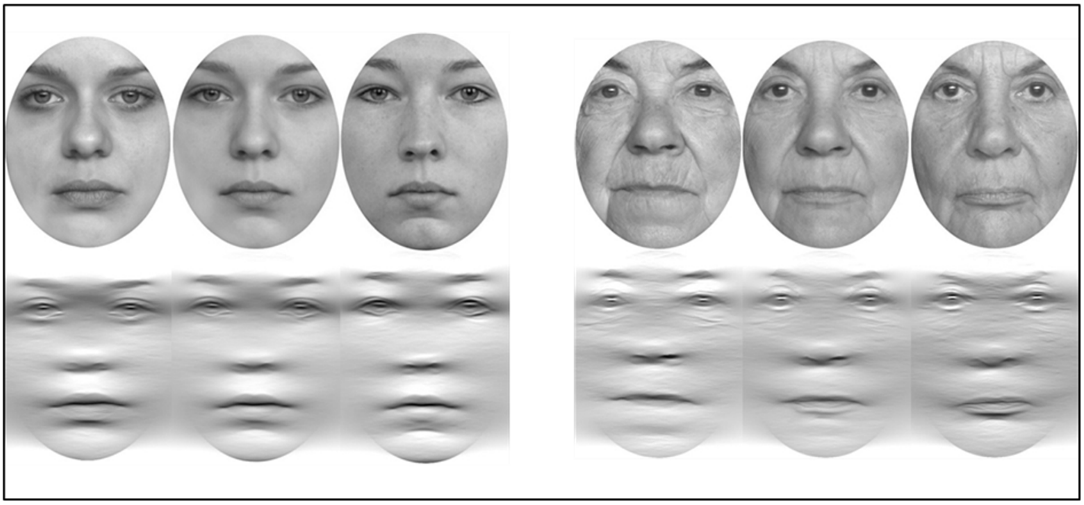

FIGURE 1 | Overview of experimental stimuli. (Upper row) young faces (on the left) and older faces are displayed containing 0, 50, and 100% target-information. **(Lower row)** filtered young faces and filtered older faces. Face stimuli were obtained from Lindenberger et al. (2007) and Langner et al. (2010).

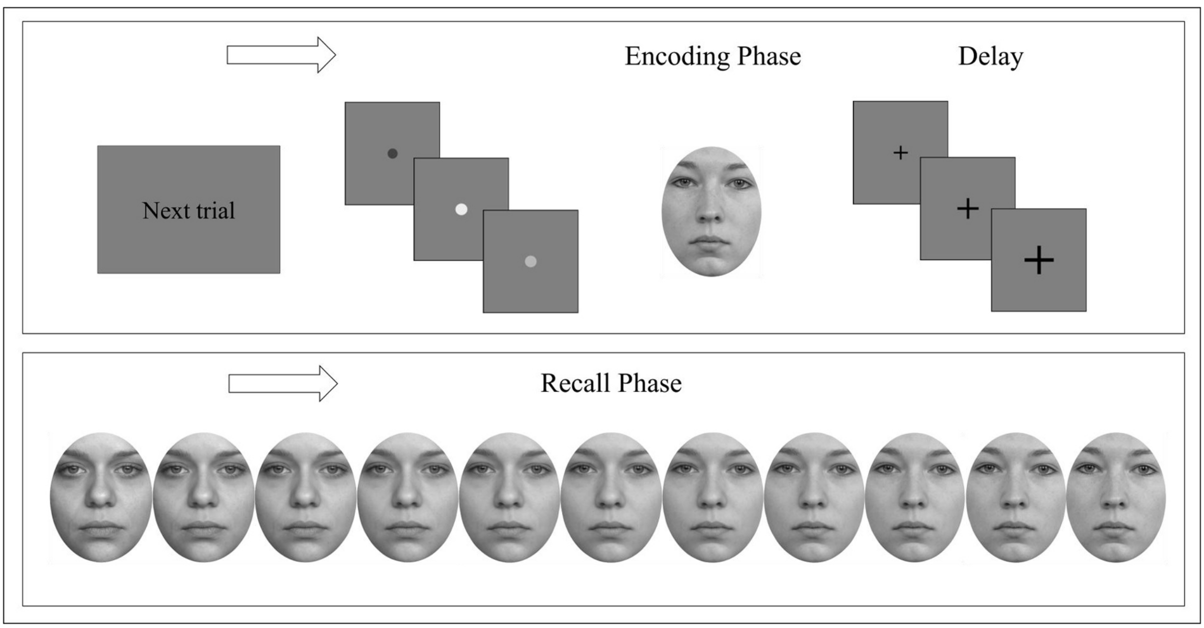

FIGURE 2 | Experimental procedure. A single trial consisted of a go-signal followed by an encoding phase of a target face presented for either 0.8 s or 8 s. Subsequent delay was accompanied by a fixation cross that became enlarged twice. Each recall phase started with a different face either merging into the previously presented target face or a (different) control face. Participants were instructed to respond as soon as they recognized the previously presented target face but to show no reaction in case of target absence. Face stimuli were obtained from Langner et al. (2010).

Both, accuracy and recognition with less target information were stressed without emphasizing either.

Each trial was followed by an intertrial interval of 3.5 s before presenting a new learning face followed by a fixation cross that became enlarged twice (6 s total). To familiarize subjects with the task participants trained with a set of stimuli that were not presented during the test session. After completing the experiment the individual digit-span was assessed.

RESULTS

Preliminary Analysis

Prior to the main analysis, in a first step, differences in general cognitive function and social contact with younger and older persons were being investigated. Since our task required participants to respond to a starting face that gradually merged into either the previously encoded target face or a control face there may have been differences considering the amount of target information necessary for making a familiar judgment between the different groups. Whether YA and OA required equal amounts of target face information was being analyzed in a second step. A 2 (age group) × 2 (stimulus age) between-subjects ANOVA was conducted analyzing the digit-span results. Three subjects (2 YA) did not complete the digit-span assessment and contact questionnaire due to a shortage of time. Those subjects were, however, included in the main analysis. There were no differences for age group [$F(1,89) = 1.276$, $MSE = 9.164$, $p = 0.262$], or stimulus age [$F(1,89) = 1.607$, $MSE = 11.547$, $p = 0.208$]. An age group × stimulus age interaction was not obtained [$F(1,89) = 0.151$, $MSE = 1.812$, $p = 0.617$].

Social contact was measured as the time spent with other persons and as the number of contact persons. Both groups reported more contact with their own age group in terms of time and number of persons. A 2 (age group) × 2 (stimulus age) × 2 (contact age: time spent with YA vs. time spent with OA) mixed-design ANOVA analyzing the time spent with younger and older persons yielded main effects for age group [YA > OA; $F(1,89) = 55.533$, $MSE = 16752.329$, $p < 0.001$, $\eta_p^2 = 0.384$] and contact age indicating more contact with younger persons [$F(1,89) = 40.392$, $MSE = 11978.961$, $p < 0.001$, $\eta_p^2 = 0.312$] but not for stimulus age [$F(1,89) = 1.600$, $MSE = 482.713$, $p = 0.209$]. Decomposition (*p*s Bonferroni corrected for multiple comparisons; $p_{crit} = 0.0083$) of a significant contact age x age group interaction [$F(1,89) = 147.522$, $MSE = 43749.574$, $p < 0.001$, $\eta_p^2 = 0.624$] yielded more contact with participants' own age compared to the other age [$M_{YA\ contact\ YA} = 55.82$, $SD = 23.44$, $M_{OA\ contact\ YA} = 4.97$, $SD = 5.62$, $t(92) = 13.882$, $p < 0.001$, $d = 3.36$; $M_{YA\ contact\ OA} = 7.96$, $SD = 10.08$, $M_{OA\ contact\ OA} = 19.00$, $SD = 22.35$, $t(92) = 3.061$, $p = 0.003$, $d = 0.38$], within either age group greater contact with the own age [$M_{YA\ contact\ YA} = 55.82$, $SD = 23.44$, $M_{YA\ contact\ OA} = 7.96$, $SD = 10.08$, $t(45) = 12.151$, $p < 0.001$, $d = 2.74$; $M_{OA\ contact\ YA} = 4.97$, $SD = 5.62$, $M_{OA\ contact\ OA} = 19.00$, $SD = 22.35$, $t(46) = 4.226$, $p < 0.001$, $d = 1.00$], and greater age-congruent contact for YA over OA [$M_{YA\ contact\ YA} = 55.82$, $SD = 23.44$, $M_{OA\ contact\ OA} = 19.00$, $SD = 22.35$, $t(92) = 7.429$, $p < 0.001$, $d = 1.52$] but no differences for age-incongruent contact between YA and OA [$M_{YA\ contact\ OA} = 7.96$, $SD = 10.08$, $M_{OA\ contact\ YA} = 4.97$, $SD = 5.62$, $t(92) = 1.771$, $p = 0.080$].

Regarding the number of persons subjects have contact with per week significant main effects for contact age [number of younger persons > number of older persons; $F(1,89) = 12.561$, $MSE = 2270.678$, $p < 0.001$, $\eta_p^2 = 0.124$] and age group [OA > YA; $F(1,89) = 6.091$, $MSE = 1636.557$, $p = 0.015$, $\eta_p^2 = 0.064$] were found but not for stimulus age [$F(1,89) = 0.069$, $MSE = 18.446$, $p = 0.794$]. There was a likewise significant age group x contact age interaction [$F(1,89) = 48.386$, $MSE = 8684.409$, $p < 0.001$, $\eta_p^2 = 0.352$]. Decomposition of this interaction yielded the same pattern as before: more contact with participants' own age compared to the other age [$M_{YA\ contact\ YA} = 25.17$, $SD = 27.02$, $M_{OA\ contact\ YA} = 5.52$, $SD = 5.41$, $t(92) = 4.888$, $p < 0.001$, $d = 1.21$; $M_{YA\ contact\ OA} = 4.46$, $SD = 4.98$, $M_{OA\ contact\ OA} = 12.32$, $SD = 10.02$, $t(92) = 4.776$, $p < 0.001$, $d = 1.05$], within either age group greater contact with subjects' own age [$M_{YA\ contact\ YA} = 25.17$, $SD = 27.02$, $M_{YA\ contact\ OA} = 4.46$, $SD = 4.98$, $t(45) = 5.768$, $p < 0.001$, $d = 1.30$; $M_{OA\ contact\ YA} = 5.52$, $SD = 5.41$, $M_{OA\ contact\ OA} = 12.32$, $SD = 10.02$, $t(46) = 4.348$, $p < 0.001$, $d = 0.88$], and greater age-congruent contact for YA compared to OA [$M_{YA\ contact\ YA} = 25.17$, $SD = 27.02$, $M_{OA\ contact\ OA} = 12.32$, $SD = 10.02$, $t(92) = 3.108$, $p = 0.002$, $d = 0.69$] but no differences for age-incongruent contact between YA and OA [$M_{YA\ contact\ OA} = 4.46$, $SD = 4.98$, $M_{OA\ contact\ YA} = 5.52$, $SD = 5.41$, $t(92) = 0.880$, $p = 0.381$].

Next the amount of target information necessary for making a familiar judgment was analyzed. As 4 OA and 1 YA were not able to respond correctly to any target trial in specific filtered conditions, no amount of target information was being recorded for these individuals and they were therefore not included in the target information analysis. A mixed-model ANOVA [2 (age group) × 2 (stimulus age) × 2 (filter) × 2 (exposure duration)] with age group and stimulus age as between measures and filter as well as exposure duration as within-subjects factors was conducted to analyze the results for target information. No main effects were obtained [age group $F(1,87) = 3.429$, $MSE = 1024.142$, $p = 0.067$, stimulus age $F(1,87) = 2.238$, $MSE = 668.586$, $p = 0.138$, filter $F(1,87) = 3.131$, $MSE = 319.959$, $p = 0.080$, exposure duration $F(1,87) = 1.260$, 92.651, $p = 0.265$] and no interactions indicating that YA and OA in either experimental condition (younger vs. older faces) did not differ regarding the amount information necessary for making a familiar judgment.

Main Analysis

In a first step a mixed-model ANOVA [2 (age group) × 2 (stimulus age) × 2 (filter) × 2 (exposure duration) with age group and stimulus age as between-subjects factors and filter as well as exposure duration as within-subjects factors was conducted analyzing the results for sensitivity (**Table 1**). Significant interactions were decomposed running multiple Bonferroni corrected comparisons.

Given our *a priori* predictions, the obtained data were then analyzed separately for each age group in a second step. The ANOVA indicated significant main effects for age group [YA > OA: $F(1,92) = 18.838$, $MSE = 30.591$, $p < 0.001$, $\eta_p^2 = 0.170$], stimulus age [older faces > younger faces: $F(1,92) = 4.000$, 6.496, $p = 0.048$, $\eta_p^2 = 0.042$], as expected greater recognition for unfiltered stimuli compared to filtered faces [$F(1,92) = 249.312$, $MSE = 137.662$, $p < 0.001$, $\eta_p^2 = 0.730$], and a significant main effect for exposure duration [8 s > 0.8 s: $F(1,92) = 48.972$, $MSE = 49.623$, $p < 0.001$, $\eta_p^2 = 0.347$].

Three significant two-way interactions were obtained (interactions involving more than two factors did not reach significance). First, a filter × stimulus age interaction [$F(1,92) = 5.286$, $MSE = 2.919$, $p = 0.024$, $\eta_p^2 = 0.054$]

TABLE 1 | Summary of means and standard deviations for sensitivity, false alarms, target information, and digit span.

	Young faces		Older faces	
	YA	OA	YA	OA
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*
Sensitivity (*d′*)				
HF 0.8 s	0.62 (1.16)	0.25 (0.66)	0.88 (0.99)	0.42 (0.70)
HF 8 s	0.92 (0.81)	0.23 (0.56)	1.29 (1.06)	1.17 (0.63)
UF 0.8 s	1.74 (1.16)	1.12 (1.00)	1.70 (0.88)	0.97 (0.87)
UF 8 s	2.73 (1.35)	1.94 (1.17)	2.96 (1.33)	2.23 (0.91)
False alarms				
HF 0.8 s	0.32 (0.24)	0.36 (0.23)	0.39 (0.25)	0.40 (0.21)
HF 8 s	0.31 (0.31)	0.34 (0.34)	0.41 (0.41)	0.33 (0.33)
UF 0.8 s	0.17 (0.17)	0.24 (0.24)	0.35 (0.35)	0.28 (0.28)
UF 8 s	0.14 (0.14)	0.16 (0.16)	0.28 (0.28)	0.23 (0.23)
Target information				
HF 0.8 s	66.96 (16.05)	66.53 (12.38)	70.59 (15.24)	67.77 (10.11)
HF 8 s	70.98 (16.02)	66.54 (11.75)	74.53 (12.42)	69.60 (10.84)
UF 0.8 s	71.85 (8.17)	67.93 (11.82)	72.22 (12.30)	73.11 (8.17)
UF 8 s	71.53 (7.11)	65.25 (9.13)	73.19 (10.47)	73.42 (7.27)
Digit span	11.70 (2.20)	11.35 (2.58)	12.68 (2.87)	11.77 (3.04)

YA, young adults; OA, older adults; HF, horizontally filtered faces; UF, unfiltered faces.

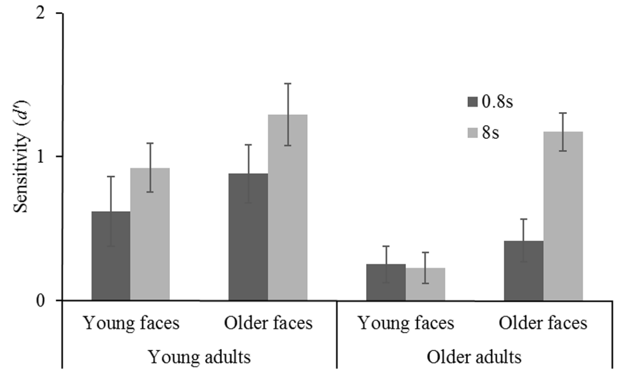

FIGURE 3 | Face recognition performance (*d′*) for short (0.8 s) and long (8 s) exposure duration as a function of stimulus age (younger faces vs. older faces) for young adults and older adults. Error bars represent standard errors.

indicates that differences between recognizing filtered and unfiltered faces is greater in younger than in older face stimuli. Second, a significant filter x exposure duration interaction was obtained [$F(1,92) = 18.972$, $MSE = 12.404$, $p < 0.001$, $\eta_p^2 = 0.171$] which indicates that an increase in exposure duration has a greater impact on sensitivity to unfiltered faces than on recognizing filtered stimuli. Decomposition of both interactions is illustrated in **Table 2**.

Finally, a significant filter × age group interaction [$F(1,92) = 4.119$, $MSE = 2.274$, $p = 0.045$, $\eta_p^2 = 0.043$] indicated, as expected, differences in sensitivity to filtered and unfiltered conditions between both age groups. This interaction will be further analyzed in the following. First, a mixed-design ANOVA [2 (age group) × 2 (stimulus age) × 2 (exposure duration)] was conducted testing for differences in sensitivity to unfiltered faces. There were significant main effects for age group [YA > OA: $F(1,92) = 17.330$, $MSE = 24.774$, $p < 0.001$, $\eta_p^2 = 0.159$] and exposure duration [8 s > 0.8 s: $F(1,92) = 55.930$, $MSE = 55.824$, $p < 0.001$, $\eta_p^2 = 0.378$], but no difference whether younger or older faces were presented [$F(1,92) = 0.247$, $MSE = 0.353$, $p = 0.620$]. Both age groups profited considerably from longer exposure duration, however, there were no biases toward own-age faces (as indicated by non-existent interactions). An analogous analysis testing for differences in sensitivity to filtered faces (**Figure 3**) indicated similar results for age group [YA > OA: $F(1,92) = 10.839$, $MSE = 99.822$, $p = 0.001$, $\eta_p^2 = 0.105$] and exposure duration [8 s > 0.8 s: $F(1,92) = 9.273$, $MSE = 6.204$, $p = 0.003$, $\eta_p^2 = 0.092$]. Additionally, a significant main effect for stimulus age was obtained [$F(1,92) = 12.138$, $MSE = 9.061$, $p < 0.001$, $\eta_p^2 = 0.117$]. A triple interaction between age group, stimulus age, and exposure duration was not significant [$F(1,92) = 2.026$, $MSE = 1.355$, $p = 0.158$, $\eta_p^2 = 0.022$].

TABLE 2 | Summary of decomposed interactions from sensitivity analysis.

	M (SD)	*M* (SD)	*df*	*t*	*p*[(a)]	*d*
Filter × Stimulus Age						
HF YF – UF YF	0.48 (0.65)	1.85 (0.93)	49	12.892	<0.001	1.73
HF YF – HF OF	0.48 (0.65)	0.94 (0.63)	95	3.529	0.001	0.72
UF YF – UF OF	1.85 (0.93)	1.98 (0.88)	95	0.700	0.486	0.14
HF OF – UF OF	0.94 (0.63)	1.98 (0.88)	45	9.279	<0.001	1.36
Filter × Exposure						
HF 0.8s – HF 8.0 s	0.54 (0.91)	0.88 (0.88)	95	2.848	0.005	0.38
UF 0.8s – UF 8.0 s	1.38 (1.03)	2.45 (1.25)	95	7.473	<0.001	0.94
HF 0.8s – UF 8.0 s	0.54 (0.91)	1.38 (1.03)	95	8.208	<0.001	0.87
HF 8.0s – UF 8.0 s	0.88 (0.88)	2.45 (1.25)	95	12.847	<0.001	1.47

[(a)]*Corrected type I error ($\alpha = 0.05/4 = 0.025$); HF, horizontally filtered faces; UF, unfiltered faces; YF, young faces; OF, older faces; d, Cohen's d.*

Testing for an Own-Age Bias

Considering that our *a priori* hypotheses concerned the question whether OA are able to recognize filtered faces when exposure duration is increased and old stimuli are added rather than solely presenting young faces, separate analyses for either age group were conducted testing for an own-age-bias with filtered faces. For YA there were no main effects [exposure duration $F(1,45) = 3.313$, $MSE = 3.003$, $p = 0.075$, stimulus age $F(1,45) = 2.070$, $MSE = 2.362$, $p = 0.157$] and no interaction [$F(1,45) = 0.073$, $MSE = 0.066$, $p = 0.788$]. For OA, however, both main effects were significant [exposure duration $F(1,47) = 7.256$, $MSE = 3.204$, $p = 0.010$, $\eta^2_p = 0.134$, stimulus age $F(1,47) = 20.194$, $MSE = 7.452$. $p < 0.001$, $\eta^2_p = 0.301$] and a significant exposure duration x stimulus age interaction was obtained [$F(1,47) = 8.360$, $MSE = 3.691$, $p = 0.006$, $\eta^2_p = 0.151$].

This interaction was decomposed further running multiple comparisons ($p_{crit} = 0.0125$, for descriptive statistics; **Table 1**). There was no difference between sensitivity to young faces and older faces when exposure duration was short [$t(47) = 0.843$, $p = 0.403$]. A large effect, however, was obtained comparing sensitivity to young and older faces with long exposure duration [$t(47) = 5.553$, $p < 0.001$, Cohen's $d = 1.59$]. This shows that an OAB toward recognizing filtered faces is observable in OA when exposure duration is long. Furthermore, the impact of a higher exposure duration interval was considerable on recognizing older faces [$t(21) = 3.245$, $p = 0.004$, Cohen's $d = 1.13$] but did not show in sensitivity to young faces [$t(26) = 0.174$, $p = 0.864$].

Since inflated false alarm rates have previously been reported in OA such an analysis was conducted. A mixed-model ANOVA [2 (age group) × 2 (stimulus age) × 2 (filter) × 2 (exposure duration)] indicated that OA made more false alarms than YA [$F(1,92) = 6.526$, $MSE = 0.612$, $p = 0.012$, $\eta^2_p = 0.066$], as well as significant main effects for filter [filtered faces > unfiltered faces: $F(1,92) = 36.513$, $MSE = 1.557$, $p < 0.001$, $\eta^2_p = 0.284$], and exposure duration [shorter duration > longer duration: $F(1,92) = 5.737$, $MSE = 0.160$, $p < 0.019$, $\eta^2_p = 0.059$] but not for stimulus age [$F(1,92) = 0.006$, $MSE = 0.001$, $p = 0.936$]. Since no interactions were obtained, differences in false alarms were not pursued any further.

Lastly, correlations coefficients (Pearson product-moment correlation, data are plotted in **Figure 4**) between filtered and unfiltered face recognition were calculated. There were three significant associations as well as one marginal correlation observable in YA [young faces: $r_{8s}(21) = 0.615$, $p = 0.002$, $r_{8s}(21) = 0.644$, $p < 0.001$; older faces: $r_{0.8s}(22) = 0.373$, $p = 0.072$, $r_{8s}(22) = 0.446$, $p = 0.029$] but none in OA [young faces: $r_{0.8s}(25) = 0.315$, $p = 0.110$, $r_{8s}(25) = -0.004$, $p = 0.985$; older faces: $r_{0.8s}$ $(20) = 0.316$, $p = 0.152$, $r_{8s}(20) = 0.071$, $p = 0.754$].

DISCUSSION

The present study was conducted to extend previous findings regarding young and OAs' ability to process faces that only contain horizontal information by two factors. First, stimulus age was introduced: YA and OA were presented with either younger or older stimuli resulting in a fully crossed design allowing assessment of an OAB which is expressed in greater sensitivity to age-congruent stimuli as opposed to age-incongruent faces. Second, a variation in exposure duration was introduced by providing subjects with both short and long encoding intervals. We found an own-age-bias in OAs' sensitivity to faces with horizontal information. Specifically, the OAB was only observable when exposure duration was long. YA' face recognition performance, however, was not affected by presenting younger or older filtered stimuli. This age-variant result was furthermore only observable when filtered faces had to be recognized. When recognizing unfiltered faces exposure duration and stimulus age had equal effects on both age groups. This finding adds to the notion that YA and OA do indeed process horizontal information differently (Obermeyer et al., 2012).

While the obtained main effects for filter and exposure duration were anticipated, the main effect for stimulus age as well as greater sensitivity to filtered older stimuli compared to filtered young stimuli were unexpected. It is hypothesized that this result is a product of the selective filtering process which may have a positive impact on older facial stimuli compared to younger faces. First, it seems plausible to assume that older faces in general contain more information compared to younger faces. Specifically, older faces differ from younger faces concerning cues of aging like wrinkles and skin tightness. Those features are likely to have passed the selective filtering process (Please compare filtered young and older faces of **Figure 1**) and may have added identity salient cues only to the older face stimuli. Consequently, recognition of filtered older faces may have been easier compared to younger stimuli. This factor may, however, have had a different impact on either age group as we will discuss below.

To further test for differences concerning the role of horizontal information in both age groups, it was investigated whether sensitivity to filtered faces is associated with unfiltered face recognition. We took high correlations as indicators for targeting similar face specific processes. Results showed that processing of horizontal information was especially efficient in YA when presented with age-congruent face stimuli. The impact of processing filtered faces on recognizing unfiltered faces was smaller when presented with older faces. An increase in exposure duration, however, was accompanied by a greater association similar to recognizing younger faces. When exposure duration was longer processing of horizontal facial cues was correlated with unfamiliar face recognition in younger adults (YA) regardless of stimulus age. However, the impact of filtered face processing on unfiltered recognition was characterized by a completely different pattern in OA. With longer exposure duration, OA' processing of horizontal information became more inefficient. Decomposing the factor stimulus age did not provide additional information about OA's ability to process horizontal information as the pattern of correlations was similar for recognizing younger or older faces. Especially when exposure duration was long, sensitivity to horizontal faces had no impact on unfiltered face recognition.

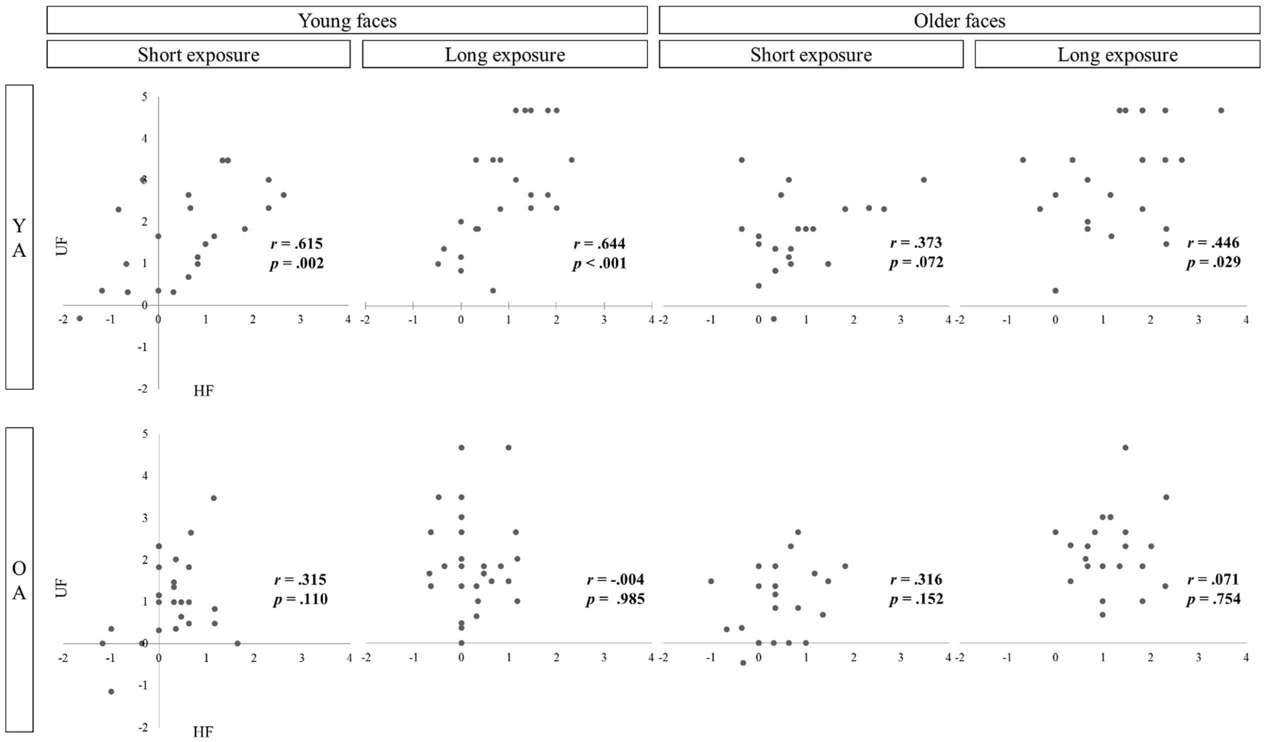

FIGURE 4 | Associations between sensitivity to filtered (HF) and unfiltered (UF) face recognition as a function of age group (YA vs. OA), stimulus age (younger vs. older faces), and exposure duration (short vs. long exposure).

There are several potential explanations for the magnitude (Cohen's $d = 1.59$) of the obtained OAB in OA with filtered faces (and the absence of an OAB in YA). Among those, previously argued cues of aging as well as the absence of correlations between filtered and unfiltered recognition in OA have to be considered. First, visual aging cues might be perceived and or processed differently by YA and OA in general. Individuals belonging to certain groups and therefore sharing a common face space (e.g., same age or same ethnic background) are likely to be more sensitive to detecting certain facial features that are specific to that group. One example to this thought is a study by Hu et al. (2014) who recently showed that both children and adults scan faces of own and other races differently. Both age groups fixated the eyes of Caucasian faces significantly longer than the eyes of Chinese faces. Conversely, the Chinese participants scanned the mouth and nose region of Chinese faces more extensively than the corresponding areas of Caucasian faces. Following that line of thought we hypothesize that OA may especially attend to aging cues when recognizing faces and/or be therefore more efficient in processing this source of diagnostic information. Certainly, YA may be susceptible to the proposed aging cued feature-based processing as a result of the selective filtering process in a similar manner as OA are. It, however, seems plausible that this proposed effect has a greater impact on OA compared to YA. Future research should therefore assess the impact on both YA and OA and to what degree it might account for the OAB. Another approach for future studies would be to compare sensitivity to older stimuli with aging cues eliminated that are not part of the general Gestalt of older faces (configural processing) with sensitivity to the same stimulus set containing all information (including natural aging features). Additionally, horizontal filter could be added as a factor which would allow quantifying the impact of aging cues in filtered vs. unfiltered older faces. A somewhat similar approach has already been pursued recently. Examining aftereffects with hybrid images that combined the structure and shape of younger, older, and same age celebrity faces Lai et al. (2013) showed that shape and texture contribute differently to different face representations, with texture dominating for age and that encoding of shape and texture seem to occur separately. As only YAs were assessed in this study future research should focus on assessing OAs with an analogous procedure.

Secondly, the obtained OAB in OA but not in YA with filtered faces might be the manifestation of different face processing mechanisms used by either age group. Since configural processing is the key feature in (unfiltered) face recognition, it is plausible to assume that the obtained associations between filtered and unfiltered recognition in YA primarily reflects this ability. As OAs likewise rely on configural processing when recognizing faces (e.g., Meinhardt-Injac et al., 2014) the absence of correlations between filtered and unfiltered conditions in OA in our study may be due to different mechanisms being targeted with filtered and unfiltered faces. In other words, it is speculated that OA do not perceive a holistic face (to the same degree as YA do) when presented with faces that only contain horizontal information.

A third finding that adds to understanding age differences in recognizing filtered faces are the obtained results of OA concerning younger faces. As shown in **Figure 3**, an increase in exposure duration did not have any impact on OA' sensitivity to younger filtered faces remaining slightly above chance level. Most likely, OA were simply not able to extract identity-diagnostic information from filtered younger faces. The question arises, why OA were able to recognize older filtered faces at the same performance level as YAs with perception of the whole face disrupted when exposure duration was long? We suggest that OA' increase in performance with increased exposure duration with filtered older faces indicates a switch to analytic processing. Additionally, as discussed above, this type of part-based processing might be particularly efficient in OA when it comes to processing older faces. An increase of analytic processing with increased exposure duration has previously been reported. Although only very little research systematically manipulated exposure duration of the study faces, Hole (1994) showed that with longer exposure duration participants switched to a feature-matching strategy as opposed to configural processing under short presentations.

Our hypothesis that OA do not actually perceive faces when confronted with filtered stimuli is moreover supported by the repeated observation of older participants reporting that they were unable to recognize anything, when initially confronted with filtered faces prior to the experiment. Two recent publications add to understanding the role of horizontal information in face recognition. Balas et al. (2015) tested 5–10 year olds with faces or objects (houses) that were either presented upright or inverted. Stimuli either contained vertical, horizontal or both vertical and horizontal information. Results showed slower reaction times to vertically filtered images than horizontally filtered images in faces but not in houses. Furthermore, older children were more likely to show such biased face detection for horizontal information than younger children. At the ages of 5–8, however, there seems to be no such bias in response time to faces that contained horizontal information suggesting development in middle childhood. Goffaux et al. (2015) recently reported convergent results testing subjects aged from 6 to 74 years of age applying a method similar to Balas et al. (2015) presenting subjects likewise with faces that either contained vertical, horizontal or both vertical and horizontal information. Face specific processing was inferred based on the FIE which was significant with faces that contained horizontal information for the age groups 12–13, 14–15, 16–17, 18–19, 20–35, and >59 years of age. At the ages of 6–7, 8–9, and 10–11 years no FIE for horizontal information was observed which in line with the results presented by Balas et al. (2015) suggesting progressive maturation of horizontal processing until young adulthood. At elderly adulthood, however, FIE development with faces that contained only horizontal information dropped notably with a non-linear function best fitting the FIE as a function of age. This finding is in line with Obermeyer et al. (2012) suggesting that OAs process horizontal information differently than YAs. Our results reported here add to this notion while offering a new scope to the role of horizontal information in YA and OA' face processing as for the first time stimulus age was being investigated systematically.

Whether the obtained correlation coefficients in YA but not in OA represent convergent configural face recognition ability cannot exhaustively be concluded from our data. Therefore, future research needs to assess whether OA' ability to recognize older faces with horizontal information is actually based on face processing mechanisms (i.e., face-specific configural processing) or whether low-level selective feature-based processing is primarily being targeted. This could be accomplished by applying an experimental approach similar to Goffaux and Dakin (2010) testing for the behavioral (face specific) signature of horizontally filtered and unfiltered age congruent-faces in OAs. Additionally, we propose that future studies add faces that are familiar to the subjects like it was initially done by Dakin and Watt (2009). Subsequent research primarily focused on perceptual processes assessing unfamiliar face recognition. To this point it remains unclear, whether OA are able to identify filtered faces they are familiar with which would involve accessing long term memory representations.

AUTHOR CONTRIBUTIONS

AS: conception and design of the work, data collection, data analysis and interpretation, drafting the article, critical revision of the article, final approval of the version to be published. SO: conception and design of the work, critical revision of the article, final approval of the version to be published. TK: conception and design of the work, critical revision of the article, final approval of the version to be published. MK: conception and design of the work, critical revision of the article, final approval of the version to be published.

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Age differences between younger and older adults in recognizing familiar faces: The impact of horizontal information

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Age differences between younger and older adults in recognizing familiar faces: The impact of horizontal information

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Abstract

Horizontal information, as a result of a selective stimulus filtering process, seems to have differential impact on younger (YA) and older adults' (OA) ability to recognize human faces. The present study extends prior research by presenting younger and older participants with age-congruent horizontally filtered and unfiltered faces they are highly familiar with (famous faces vs participants' own faces). While YA recognized their own faces better than famous faces (self-face advantage) as expected, stimulus filtering had a detrimental effect on OA's ability to self-recognize. Additionally, filtered and unfiltered face recognition was found to be associated in YA indicating a global recognition ability, while no such interrelation was found for the older age group suggesting that different processes are being targeted in the elderly. It is concluded, that the basic ability to process faces according to the configural information within them is impaired in older adults when only horizontal information is available.

Keywords: face recognition, aging, horizontal information, familiarity, self-face advantage

Age differences between younger and older adults in recognizing familiar faces: The impact of horizontal information

A substantial amount of publications indicates that face processing continuously improves during childhood and declines with age. While some researchers propose face processing is mature as early as after 4 years of experience with faces (de Heering, Rossion, & Maurer, 2012), others report ongoing recognition improvement until the age of 30 (Germine, Duchaine, & Nakayama, 2011). At a higher age[1], face recognition becomes less accurate (Grady, 2002; Hildebrandt, Wilhelm, Herzmann, & Sommer, 2013; Searcy, Bartlett, & Memon, 1999; Crook & Larrabee, 1992; Bäckman, 1991). This decrease in accuracy cannot be attributed to general-cognitive ability (Hildebrandt, Wilhelm, Schmiedek, Herzmann, & Sommer, 2011). Differences in reaction times (Grady, Randy McIntosh, Horwitz, & Rapoport, 2000) are assumed to rather be a product of decision making than an indicator of a decrement in sensory and perceptual processing speed (Habak, Wilkinson, & Wilson, 2008; Pfütze, Sommer, & Schweinberger, 2002). A first significant decline at 50 years of age has been reported with a second, more pronounced decline occurring at the age of 70 which points toward an accelerated adverse development in OA (Crook & Larrabee, 1992). Interestingly, processing of other complex stimuli like objects or scenes were found to be less affected by aging (Meinhardt-Injac, Persike, & Meinhardt, 2014; Park, Puglisi, & Sovacool, 1983; Craik & Jennings, 1992). This item-specific decrement of recognition performance therefore highlights faces as especially critical stimuli in older adults. Other than objects, which are processed in a feature-based manner (analytic processing), faces are processed primarily according to the configural information within them (Hole & Bourne, 2010; but see Burton, Schweinberger, Jenkins, & Kaufmann, 2015 discussing usage of the term configural information). Holistic processing is considered as one of three types of configural processing, which refers to the Gestalt-like integration of facial features as a whole (for an overview see e.g., Hole & Bourne, 2010). Although holistic processing has recently found to be substantially delayed in OA (Wiese, Kachel, & Schweinberger, 2013), this key feature seems to be preserved until a high age (Diamond & Carey, 1986; Farah, Wilson, Drain, & Tanaka, 1998; Meinhardt-Injac, Persike, & Meinhardt, 2014; Richler & Gauthier, 2014). Hence, research indicates that the basic processing mechanisms involved in face recognition seem to be preserved in OA, but become less efficient.

A factor that focuses on stimulus characteristics has recently been suggested to account for face recognition differences between YA and OA. Dakin and Watt (2009) introduced a method that reduces facial information by filtering an image and thereby breaking it down to its basic components. Depending on the applied filtering process, images can be selectively reduced to only retain visual information of a certain orientation and thereby simulating what information would be passed by V1 neurons (Hubel & Wiesel, 1968) tuned to a specific visual structure. Moving from horizontal to vertical, the authors demonstrate preferential processing of information that are aligned horizontally with target detection sensitivity continuously declining reaching lowest performance at vertical. This finding suggests that facial identity features are largely conveyed via mechanisms tuned to a horizontal visual structure. When all but horizontal information of a facial image are removed a vertically aligned clustering of light and dark regions along a vertical axis is generated (Please see Figure 1). This type of pattern, which has been labelled 'bar code', is only observable for faces. When all but horizontal information is removed from images displaying objects or natural scenes, no such clustering emerges (Dakin & Watt, 2009). Follow-up studies conducted by Goffaux and Dakin (2010) reported face specific effects for horizontal but not for vertical information as indicated by different face-specific phenomena (e.g., the face inversion effect, FIE, Yin, 1969) which demonstrate that other than objects, human faces are mainly processed configurally.

Adding a developmental perspective, Obermeyer, Kolling, Schaich and Knopf (2012) assessed a younger and an older age group with horizontally filtered, vertically filtered and unfiltered faces. Although the results by Goffaux and Dakin (2010) could be replicated for YA, a different quantitative pattern for OA was obtained as there was no preferential processing of horizontal information over vertical information observable. Accordingly, the authors proposed that processing of horizontal information may be less efficient in OA.

Two very recent publications likewise assessed the role of horizontal information in face recognition from a developmental point of view. Testing children between the ages of 5-10 years, Balas, Schmidt, and Saville (2015) showed that a bias towards horizontal information over vertical information was only observable for older children. Hence, the authors conclude that representing faces with horizontal information continues to optimize during middle childhood. Convergent results were recently reported by Goffaux, Poncin, and Schiltz (2015) who tested participants between the ages of 6-74 years of age applying a method similar to Balas et al. (2015). With the size of the FIE indicating reliance on face-specific processing (faces were presented upright and inverted either containing horizontal, vertical or both horizontal and vertical information) the authors found progressive maturation of horizontal processing until young adulthood. However, the size of the FIE with horizontal information dropped notably from young to elderly adulthood suggesting a key role in especially younger adults' face recognition.

Other than basic early perceptual mechanisms as suggested by the bar code model (Dakin & Watt, 2009), the level of face related expertise (familiarity) is a factor which likewise needs consideration when investigating age-related differences in face recognition. In general, unfamiliar faces and familiar faces (celebrities or personally familiar faces) can be differentiated which have been proposed as qualitatively different (Burton & Jenkins, 2011; Johnston & Edmonds, 2009; Zimmermann & Eimer, 2013; Bruce & Young, 2012). While representations derived from unfamiliar faces are described as low-level image descriptions based upon pictorial information (Hancock, Bruce, & Burton, 2000), processing and encoding of familiar faces is characterized as robust and more flexible (Tong & Nakayama, 1999). According to Bruce and Young (1986) only after repeated exposure to a face across a variety of expressions and angles, a structural code is formed and stored in a face recognition unit (FRU). An activation of this unit will occur irrespective of viewing angle when the face is seen, but only if a threshold level of activation is reached that exceeds all other FRUs. The formation of a representation based upon pictorial information (unfamiliar faces) and structural codes (familiar faces) helps explaining quantitative differences between the two categories that have frequently been reported: famous and personally familiar faces are processed faster and more accurately than unfamiliar faces (Bruce et al., 1999; Campanella, Hanoteau, Seron, Joassin, & Bruyer, 2003; Ellis, Shepherd, & Davies, 1979). A theoretical distinction between familiar and unfamiliar faces derives most clearly and reliably from behavioural research (Burton & Jenkins, 2011). Internal features (eyes, nose, and mouth) were shown to be more important than external features (outer face shape and hair) when recognizing familiar faces. Conversely, an external feature advantage for unfamiliar faces has been demonstrated within the literature (Ellis, Shepherd, & Davies, 1979; Newcombe & Lie, 1995; Campbell, 1999; though see Young, Hay, McWeeny, Flude, & Ellis, 1985).

While increased exposure duration to a face plays a pivotal role in establishing familiarity with unfamiliar faces resulting in higher accuracy (Memon, Hope, & Bull, 2003; Reynolds & Pezdek, 1992), differences in face recognition within the category of familiar faces are of more complex nature. Though familiarity is obviously established through repeated exposure, encoding modalities are quite different for famous and personally familiar faces. Obviously, most people will not encounter Brad Pitt or Madonna in person. Developing familiarity with particular celebrity faces will be limited to media like television, internet, and newspapers. On the one hand representations of celebrities might therefore differ regarding their formation or may even be represented differently due to encoding modalities. On the other, one might argue that familiar face recognition is almost exclusively assessed via images or videos – the same modalities available for encoding famous faces.

A step further in investigating familiar face recognition would be adding a person's own face which has been investigated rather sparsely in previous research. Like faces relative to objects, a person's own face has been proposed as special. When compared to other faces quantitative differences favouring self-face have been observed by various researchers over both famous (Keenan, Freund, Hamilton, Ganis, & Pascual-Leone, 2000; Caharel et al. 2002) and personally familiar faces (Keenan et al., 1999; Ma & Han, 2012; Tong & Nakayama, 1999; Caharel, Fiori, Bernard, Lalonde, & Rebaï, 2006; Keyes & Brady, 2010; Keyes, Brady, Reilly, & Foxe, 2010). Keenan et al. (1999) had participants categorize their own face, a familiar other's or a stranger's face as quickly as possible by pressing one of three buttons either with their left vs their right hand. Since reaction times were significantly faster when the self-face was categorized using the left hand compared to the other five conditions the authors stress the possibility of hemispheric specialization for self-face recognition indicating qualitative differences. In contrast, predominant activation of left frontal areas in a similar task has been found (Kircher et al., 2000, 2001). Brady, Campbell, and Flaherty (2004) likewise report left-hemispheric advantages for self-face recognition. Platek et al. (2006), Taylor et al. (2009) and Keyes and Brady (2010), however, emphasize bilateral activation for self-face processing. Reviewing pertinent research, Gillihan and Farah (2005) conclude that for self-face recognition a clear pattern of anatomical localization has yet to emerge (for a more recent review, see Devue & Brédart, 2011). Tong and Nakayama (1999) had participants perform a visual search task by either identifying their own vs unfamiliar faces. Participants were exposed to unfamiliar faces hundreds of times, trying to establish familiarity. The advantages in processing speed (quantitative differences) for self-face however persisted. Summing up, some studies do detect preferential self-recognition others do not (e.g., Brédart & Devue, 2006; Kircher et al., 2001). For an overview, see Gillihan and Farah (2005) reviewing which other aspects of the self may be considered as special.

So far, the role of horizontal information in face recognition has only been investigated with material that displayed younger adult stimuli. Recent research however suggests preferential processing of own-age faces relative to faces of other ages (Anastasi & Rhodes, 2005; Hills & Lewis, 2011), a finding which has been labelled "Own-Age Bias" (OAB). Meta-analytic findings quantify differences in target detection sensitivity due to the OAB at an effect size of $g = 0.37$ (medium effect; analogously interpretable to Cohen's *d*) in favor of same-age compared with other age-faces (Rhodes & Anastasi, 2012). Since the majority of studies conducted in the past presented college-aged targets when assessing age differences ignoring superior recognition of own-age faces (Anastasi & Rhodes, 2005), obtained age differences may have been overestimated due to disadvantaging stimulus material burdening OA.

The goal of the present study is to assess whether OA are able to recognize horizontally filtered faces similar to YA when they are provided with faces of their own age and are more familiar with the stimulus material presented than in previous studies. Self-face stimuli will serve as an especially high level of facial expertise. Although some studies have shown equal performance levels regarding self-face recognition and personally familiar faces (Brédart & Devue, 2006) to our knowledge, no study has yet shown inferior performance recognizing oneself relative to any other familiar or unfamiliar class of faces. As ceiling effects are likely to occur with very familiar stimulus material, morphed face sequences will be used. An unfamiliar starting face will gradually merge into either a target face (self-face or famous face) or into another unfamiliar face (false alarm trials for controlling response biases) with earlier recognition along the morph continuum indicating better recognition performance. We expect that filtered face recognition will require more target information than unfiltered recognition. Likewise, target detection sensitivity (*d'*) is expected to be greater for unfiltered faces compared to filtered faces. Self-face recognition should be greater than recognizing famous faces (self-face advantage) which we predict to result in both greater sensitivity and less target information (i.e., earlier recognition along the morph continuum). This result is expected regardless whether faces are filtered or unfiltered. Simple comparisons indicating the magnitude of an expected self-face advantage are planned separately for unfiltered and filtered faces. Associations between conditions will be tested trying to answer the question whether filtered face recognition predicts unfiltered recognition indicating converging face specific processes.

Methods

Design

As YA and OA were exposed to age-congruent stimuli, separate analyses were conducted for either age group with the within-subject factors filter (filtered vs unfiltered faces), and familiarity (famous faces and self-faces). Both target detection sensitivity (*d'*= Z(hit rate) - Z(false alarm rate)) and amount of target-information (morph level) were dependent variables.

Participants

Twenty-three YA (14 female) aged between 18 and 36 years (*M* = 22.16 years, *SD* = 4.26 years) and 22 OA (13 female) aged between 62 and 83 years (*M* = 68.45 years, *SD* = 5.44 years) participated in the study. All participants were students of Frankfurt Universities: YA were undergraduate students of Frankfurt Goethe-University, OA attended the Frankfurt University of the third age, a program for education at a higher age. All participants were of Caucasian heritage and had normal or corrected-to-normal vision. Experiments were approved by the faculty ethics committee and were in line with APA guidelines according to the ethical principles of psychologists and code of conduct.

Materials

Two experiments were conceptualized, one for YA and another for OA. Because the experimental design required participants to recognize their own faces, a male and a female stimulus version was constructed (female participants were presented with female faces and vice versa). On a first appointment, a photograph of the participant's face was taken. Participants were photographed with a digital camera (Sony DSC-HX5) in a frontal view, with glasses removed if necessary, and displaying a neutral expression. Participants were assured that their individual photographs would be stored safely and not be published or displayed publicly (the two participants who are displayed in Figure 1 gave written consent to have their faces published). Computerized tests in this study were programmed using E-Prime 2.0 (Psychology Software Tools, Inc., Sharpsburg, PA, USA) and presented on a 22'' computer screen (LG 2210PM; resolution: 1680x1050) at a viewing distance of approximately 60cm. Faces were obtained using different databases (Langner, Bijlstra, Wigboldus, Hawk, & van Knippenberg, 2010; Minear & Park, 2004; Lindenberger, Ebner, & Riedinger, 2007). Famous faces were searched via internet aiming at a pool of celebrities who would be highly familiar (from television, movies, music, and sports) to respective age groups. Search parameters included a minimum pictorial resolution of 800x600 pixels (excluding wallpapers or other high quality studio photographs) aiming at equalling the unfamiliar faces used (central view and neutral expression). Four young raters (2 male, 2 female, M = 27.75 years; SD = 5.19 years) chose 16 famous female as well as 16 male faces (presented male celebrities: M = 31.88 years, SD = 6.32 years; female famous faces M = 30.75 years, SD = 7.28 years). Four older raters (2 male, 2 female, M = 56.75; SD = 17.67) picked old celebrities accordingly (male celebrities: M = 65.63; SD = 4.98; female celebrities

M = 68.50; *SD* = 8.01). A second image of each chosen famous face was searched via internet and used for determining a participant's individual pool of famous faces in two pretesting procedures. Pre-test stimuli were converted to grey scale and resized to a standard width of 600 pixels with height slightly varying in order to maintain the aspect ratio. All images (i.e., unfamiliar, famous, and self-faces) used in the experiment were edited using Gimp 2.8 (The Gimp Team, www.gimp.org). Elliptical outer forms were cropped and converted to grayscale. Width of faces was kept constant at 400 pixels with height slightly varying. Stimuli were mounted on a white 800x600 pixels background. Differences in contrast and luminance were equalized as best as possible, conspicuous marks, facial hair, scars, etc. were removed. Figure 1 illustrates samples of the different stimulus classes.

(Please insert Figure 1 about here)

The experiment consisted of 96 trials (half filtered, half unfiltered stimuli). In half of the trials, a target was present (hits) the other half were false-alarm trials. There were 24 target trials (16 famous faces, 8 own-face trials) and 24 corresponding false alarm trials. A greater number of celebrity stimuli was included since participants were likely to be unfamiliar with particular famous faces used in the experiment (particular trials participants were unfamiliar with and the corresponding morph level were excluded from data analysis). A hit-trial was comprised of 2 faces: a familiar face that served as a target face and a starting face that gradually merged into the target face. A false alarm trial was comprised of a third face as the starting face merged into a different face than the target face. From the entire set of unfamiliar faces, stimuli were assigned randomly to serve as starting faces. Famous female faces that contained makeup were matched with similar starting and control faces (See Figure 1). Starting faces changed on each trial. Morph continua (videos) were created using Morpheus Photo Morpher v3.16 Industrial (Morpheus Software LLC, Santa Barbara, CA, USA) with a duration of 20 seconds (for analogous assessment see e.g. Keenan et al., 2000;

Kircher et al., 2001). Stimuli displaying only horizontally aligned information were generated using Matlab 7.13 (The Mathworks, Inc., Natick, MA, USA). The filtering process includes breaking down a stimulus to its basic components by Fourier transforming it and multiplying the Fourier energy with an orientation filter (wrapped Gaussian profile with a standard deviation of 20°) allowing only horizontal information to pass (for further details see Dakin & Watt, 2009). To screen for cognitive function, participants completed the WAIS-R Digit-Span subtest (Tewes, 1991). The WAIS-R Digit-Span subtest involves remembering growing chains of numbers forward and backward and assesses working memory. Media exposure (television time, cinema visits, hours reading magazines) was recorded applying single-item-measures followed by a general evaluation of the experiment on 5-point-scales including one item measuring the perceived dissimilarity between the particular self-face stimulus used in the experiment and the participant's subjective self-face representation ("my face looks different than the photograph in the experiment"). Another item assessed the general degree of interest in famous persons ("I am interested in celebrities").

Procedure

Prior to the experiment, two pretesting procedures assessed individual familiarity with the famous faces. 16 famous faces for both genders were presented in two separate blocks finishing with the participant's own gender. Each celebrity image was shown for 6 seconds at the most if no reaction occurred. Participants were instructed to press the space-bar if they were familiar with a displayed face. Next, an input box appeared on the screen requesting participants to identify the displayed person by either typing in the name or to provide other semantic information that would indicate familiarity (e.g., "German chancellor" for Angela Merkel). In the sex-matching block, an additional picture of the participant's own face was added to ensure individuals were exposed to their own face once before performing the experiment. Computerized assessment was followed by a paper and pencil test subjectively rating the degree of familiarity with each celebrity face on 8-point scales ranging from "not at all" to "very well". The experimental session lasted approximately 30 minutes with no break and could be aborted by the participant at any time (all participants completed the experiment). Filtered and unfiltered trials were presented randomly. Participants were instructed to press one marked key of a standard keyboard for their own face yet another for famous faces as soon as they recognized a target but to show no reaction in case of target absence for each session. No feedback was given. Both, accuracy and recognition with less target information were stressed without emphasizing either. Each new morph sequence was initiated with an intertrial interval announcing "Next Trial" (2s) followed by a 2s go-signal (a red dot changing to yellow and then to green). After completing the experiment, a questionnaire regarding media exposure was taken.

Results

Prior to the main analysis, results of general cognitive function, familiarity with the stimulus material, and media exposure were tested for age differences between YA and OA. Since participants sporadically did not answer all survey items, sample sizes slightly varied within particular analyses. There were no age differences for digit span (YA: $M = 11.70$, $SD = 2.20$; OA: $M = 11.77$, $SD = 3.04$; $t\ (43) = -.0.98$; $p = .923$). Familiarity with the famous faces presented as indicated by subjective ratings was high for both age groups (YA: $M = 6.34$, $SD = 0.85$; OA: $M = 6.51$, $SD = 1.20$). An independent sample t-test showed no difference in baseline-familiarity with referential celebrity faces ($t\ (43) = 0.568$; $p = .573$). On average 3 famous faces (YA: $M = 3.45$ faces ($SD = 2.67$); OA: $M = 3.17$ ($SD = 1.86$); $t\ (43) = 0.793$; $p = .432$) were unfamiliar to either age group – sensitivity results and recorded morph levels of the corresponding trials were excluded from data analyses. Aside cinema visits per month (YA: $M = 10.48$, $SD = 9.89$; OA: $M = 4.36$, $SD = 4.66$; $t\ (41) = 2.576$; $p = .014$, $d = 0.84$) items measuring media exposure did not indicate differences between OA and YA (television hours per day: YA: *M* = 2.84, *SD* = 4.05; OA: *M* = 2.21, *SD* = 1.29; *t* (42) = 0.08; *p* = .936; hours reading magazines: YA: *M* = 1.35, *SD* = 4.21; OA: *M* =1.55, *SD* =.97; *t* (42) = 0.217; *p* = .829. Both age groups indicated equal general interest towards celebrities (YA: *M* = 3.18, *SD* = 1.33; OA: *M* =3.55, *SD* =1.14; *t* (42) = 0.217; *p* = .337) and rated dissimilarity between their own faces and the respective experimental self-face stimulus equally high ("my face looks different than the photograph in the experiment": YA: *M* = 2.60, *SD* = 1.22; OA: *M* =3.05, *SD* =1.47; *t* (41) = 1.112; *p* = .273).

(Please insert Figure 2 about here)

As shown in Figure 2, sensitivity to filtered faces was considerably lower compared to unfiltered recognition within both age groups. In YA, sensitivity to self-stimuli was greater compared to famous faces regardless whether faces were filtered or presented with all facial information. This holds true for OA only when faces were unfiltered. For filtered stimuli however, OA behavioural pattern is reversed as sensitivity to famous faces is higher compared to participants' own faces, which ranges around chance level.

As younger and older adults were each presented with age-matching stimuli, separate 2 (filter) x 2 (familiarity) ANOVAs were conducted for each age group testing for differences in sensitivity. For YA, main effects for filter (F (1, 22) = 124.612, MSE = 83.825, $p < .001$, $\eta_p^2 = .850$) and familiarity (F (1, 22) = 21.241, MSE = 8.985, $p < .001$, $\eta_p^2 = .491$) were observed but no interaction (F (1, 22) = 0.022, MSE = 0.014, $p = .884$). For OA, a main effect for filter was observed (F (1, 21) = 84.743, MSE = 70.205, $p < .001$, $\eta_p^2 = .801$) but not for familiarity: F (1, 21) = 0.203, MSE = 0.206, $p < .657$). Additionally, a significant filter x familiarity interaction was obtained (F (1, 21) = 9.333, MSE = 5.960, $p = .006$, $\eta_p^2 = .308$).

(Please insert Table 1 about here)

Table 1 illustrates planned comparisons of both familiarity levels within each age group testing for a self-face advantage. For both age groups a self-face advantage was observable when stimulus material was unfiltered. Likewise, filtered famous face recognition significantly differed from filtered self-face recognition in YA. For OA however, the expected self-effect was reversed (famous faces > self-face). One sample t-tests of OA' sensitivity compared to zero indicated significant differences for the famous faces condition (t (21) = 6.566; p < .001) but not the self-face condition (t (21) = .366; p < .718) demonstrating, that OA cannot recognize this stimulus type.

(Please insert Figure 3 about here)

Regarding the amount of target information (Figure 3), the quantitative pattern again differs between both age groups regarding filtered stimuli: YA recognized their own faces with less target information compared to famous faces as expected which holds true for both filtered and unfiltered faces. Again, OA displayed a reversed response behaviour, as more target information was needed to make a familiar judgement for their own faces compared to familiar faces when only horizontal information was available. For each age group a 2 (filter) x 2 (familiarity) ANOVA was conducted testing for differences in the amount of target information. Four OA and one YA were not able to respond correctly to any target trial in the filtered self-face condition. Consequently, no amount of target information was being recorded for these five individuals and they were not included in the respective target information analysis. For the younger age group, main effects for filter (F (1, 22) = 31.724, MSE = 2585.653, p < .001, η_p^2 = .602) and familiarity (F (1, 22) = 18.838, MSE = 1132.201, p < .001, η_p^2 = .473) were observed and no interaction (F (1, 22) = 0.416, MSE = 33.595, p = .526). Within the older age group, likewise main effects for filter (F (1, 21) = 7.240, MSE =

598.697, p = .016, η_p^2 = .312) and familiarity were obtained (F (1, 21) = 7.355, MSE = 671.522, p = 0.015) and additionally a filter x familiarity interaction (F (1, 21) = 11.464, MSE = 545.653, p = .004, η_p^2 = .417).

Again, each age group was tested separately for a possible self-face advantage (Table 1). Within the group of YA, a self-face advantage was not observable for filtered faces but for unfiltered faces. While the amount of target information significantly differed with filtered stimuli for OA indicating a "self-face-disadvantage" this reversed pattern was not obtained for unfiltered faces but no self-face advantage was found. The observed effects with both dependent measures were very similar within either age group which can be envisioned when mentally mirroring the vertical axis of Figure 3 which would result in greater morph-level representing poorer performance.

For target information percentage, correlation coefficients were calculated testing associations between particular conditions within either age group. As illustrated in Table 2, significant correlations were obtained only for YA. For example, the amount of target information necessary for recognizing filtered famous faces was correlated with recognizing participants' own faces in both filtered and unfiltered presentation conditions. There were, however, no significant correlations within OA - neither between filtered and unfiltered conditions nor between the two different levels of familiarity.

(Please insert Table 2 about here)

Lastly, a high correlation between sensitivity to unfiltered self-face recognition and perceived self-face dissimilarity ("my face looks different than the photograph in the experiment") was obtained for OA (r (19) = -.632, p < .01) but not for YA (r (20) = -.063, p = .785).

Discussion

We pursued the question whether presenting younger and older adults with filtered faces and unfiltered faces of their own age generates similar results with different levels of facial familiarity. Younger and older celebrity faces and self-face images were used providing stimulus material that was expected to be especially familiar to participants. Specifically, face recognition sensitivity was expected to be even greater for participants' own face with less target information necessary for making a familiar judgement compared to the famous faces condition. Although there were great quantitative differences between filtered and unfiltered recognition in YA for both dependent measures, the pattern is largely preserved when comparing both levels of familiarity. A clear self-face advantage over famous faces was observed for unfiltered faces with both dependent variables. In the filtered condition, performance between self-face and famous faces differed significantly for sensitivity, but the same comparison with amount of target information shows marginally significant. This result indicates that quantitative differences between both levels of familiarity do not transfer equally due to the filtering process resulting in smaller effect sizes between HF conditions. Overall however, the obtained results for YA were as expected and are consistent with previous findings (Dakin & Watt, 2009; Goffaux & Dakin, 2010; Obermeyer et al., 2012).

OA' results are less clearly interpretable. While an increase in familiarity from famous to self-face resulted in greater sensitivity with unfiltered stimuli as hypothesized, the reversed pattern was observed, when faces were filtered demonstrating a self-face disadvantage. No differences in the amount of target information were obtained when faces were unfiltered, which likewise stands in contrast to the response behaviour displayed by the younger age group. OA made their decision along the morph continuum with significantly less target information, when a filtered famous face had to be recognized compared to participants' own faces with horizontal information. The latter finding seems plausible insofar, as OA' sensitivity to filtered self-face stimuli does not exceed chance level while performance with filtered famous faces was found to be significantly different compared to zero. In sum, our results show, that OA were not able to self-recognize when a self-face image only displayed horizontal information.

Since horizontally filtered stimuli are thought to be processed similar to unfiltered faces (Dakin & Watt, 2009; Goffaux & Dakin, 2010) we did expect to obtain correlations between filtered and unfiltered conditions. The observed absence of associations between experimental conditions within OA leaves room for different interpretations. Earlier recognition of filtered faces was not associated with unfiltered recognition, as opposed to YA, which might indicate that different processing mechanisms are being targeted within age groups. It seems plausible to assume that the bandwidth of inter-individual differences and the amount of diagnostic information is greater when a participant is presented with an unfiltered (naturalistic) face compared to a filtered face. However, from a test theoretic standpoint, we would expect that some inter-individual variability as a result of presenting unfiltered faces would convergently be observable for the amount of target information with filtered faces. Following this line of argumentation, it stands to debate, whether both versions of faces measure the same underlying construct in OA.

Inferring from the obtained correlations between filtered and unfiltered conditions, it is plausible to assume that similar face-specific processes were being targeted only in YA while OA were not able to use all the visual information available to them. We propose, that the filtering process reduces facial information to a degree that allows YA to still use configural processing while being disrupted in older adults similar to e.g., face inversion. Megreya and Burton (2006) reported high correlations between matching unfamiliar faces presented upright and inverted famous faces. However, for familiar faces, no association between inversion and upright presentation was found. Since inversion has shown to primarily disrupt configural processing, their results suggested that in unfamiliar face recognition, configural information is not used (Johnston & Edmonds, 2009). Despite OA' ability to apply configural processing being potentially disrupted in our study, analytic processing of pictorial codes was likely disrupted in both age groups, since individual features become evidently harder to recognize when faces are filtered (please see Figure 1). Additionally, other than face-matching tasks that present a target face and probe face simultaneously or shortly delayed and thereby allowing a scanning for visual cues, our experiment required participants to access face memory and thereby minimizing perceptual face processing (Megreya & Bindemann, 2015). Compared to other studies assessing the role of horizontal information, our task differed methodologically from Goffaux and Dakin (2010) and Goffaux et al. (2015) as the authors implemented face matching tasks with unfamiliar faces (minimizing the memory component), but is quite similar to the work done by Dakin and Watt (2009) who had participants identify famous faces.

In sum, differences in OA' performance with filtered faces may to a less extent reflect variability in face recognition but rather inter-individual differences in recognizing degraded visual material. Clearly, future research needs to explore these assumptions more thoroughly. Whether the correlations in YA are mainly a product of a common underlying (face-specific) factor or in part due to the applied method cannot be differentiated in the study reported here. The finding that OA' sensitivity to famous faces exceeded chance level suggest that those faces could be recognized to some degree. This result may reflect slight differences within the stimulus material despite trying to equalize all faces (unfamiliar faces, famous faces, participants' own faces) as best as possible. A preferable approach for future research would be to hold pictorial differences constant by for example comparing recognition of personally familiar faces and self-faces that were all photographed with the same camera.

Aside the different impact of the filtering process on face recognition performance in YA and OA sensitivity to unfiltered faces was notably greater for younger participants. Although analogous findings have been reported considering tasks assessing face memory (Bäckman, 1991; Boutet & Faubert, 2006; Germine et al., 2011) there are possible explanations that might account for this observation. First, presenting morphed sequences might have been more unusual for OA. Future research could contrast discrete presentation of successive frames with the method reported here. Second, individual familiarity with the famous faces may have been overestimated by the older age group though quantitatively there was no difference as indicated by pretesting procedures. Likewise, media exposure did not yield notable differences between both age groups overall, however it seems possible that an idolizing effect has a greater performance enhancing effect in YA compared to OA, which could likewise be a question for future studies. The basic idea would be that at a younger age, celebrities like actors, singers, or sports athletes might especially function as role models which could be less pronounced in OA. Another approach would be testing a stimulus pool of faces between 40 and 50 years of age, which might reduce prior supposable effect and would additionally include the advantage of presenting both age groups with the same stimulus material. Ideally, future studies could assess younger, middle-aged, and older adults with all stimulus categories testing for a potential own-age bias with filtered faces in a fully crossed design. Such an experimental design would furthermore have the advantage of holding the distinctiveness of the faces themselves constant, as faces of different age categories may differ in the amount of identity information carried by horizontal contours.

The role of self-recognition in OA has to be considered in future research. A finding that supports a special role of self-face stimuli was the absence of association between famous and self-face recognition for unfiltered faces in OA as opposed to correlations in YA which might indicate that an intervening mechanism is present in the older age group. So far, a special role of self-face recognition has mainly been inferred from quantitative superiority over other categories of faces. In our study, the likelihood of discovering a self-face advantage may have increased due to priming effects and more image specific processing as one self-image was used while testing different celebrity faces. This factor makes it however even more surprising, that performance with the filtered self-face image was so poor in OA. A common denominator of other studies cited above, including our own results, was participants being aged between 18 and 36 years. To this point, studies assessing self-face recognition in OA are very rare. To our knowledge, the only research comparing self-face recognition with other categories of faces in OA is a very recent study by Kurth, Moyse, Bahri, Salmon, and Bastin (2015). In two experiments the authors compared mild Alzheimer's disease (AD) patients (experiment 1) and moderate AD patients (experiment 2) with healthy older participants. Participants' own faces, a familiar face (spouse) and unknown faces were presented measuring both accuracy and reaction times in a first experiment and solely accuracy in a second experiment (since the authors operationalized unfamiliar face recognition differently from the other two categories, an assessment of a potential self-face advantage is discussed comparing only self-face recognition and familiar face recognition in the following). Results indicated no self-face advantage in either healthy control group, the mild AD group, or the moderate AD group. The authors comprehensibly speculate that over time, spouses' faces may become as relevant as self-faces.

Our data suggests that on the one hand, both age groups equally rated their own face as looking different from the self-face stimuli used in the experiment. This may in part be due to the standardized outer form of the stimulus material which might be particularly striking concerning a person's own face. On the other hand, only in OA a high correlation between sensitivity to unfiltered self-face recognition and this perceived self-face dissimilarity was obtained. This negative impact on performance needs further investigation including the hypothesis of a greater impact of outer facial features on familiar face recognition in OA compared to YA. Alternative explanations could furthermore be a greater discrepancy between the mental representation of the self and the actual reflected visual information (e.g. from a photograph or a mirror) in OA versus YA. OA' own representation might for example be represented in a younger, more favourable and self-worth enhancing own face version.

Summing up, aside the results presented by Obermeyer et al. (2012) and Goffaux et al. (2015), this piece of research provides additional data supporting the differential role of horizontal visual information in YA and OA. Our finding, that OA were unable to recognize their filtered self-faces, questions the role of horizontal information for face processing at a higher age. Possibly, OA' impaired performance is a result of less efficiently functioning (or degenerated) V1 neurons tuned to that orientation. This would suggest, that less information is available when integration of identity is being carried out at subsequent processing stages. This explanation would apply to the findings by Obermeyer et al. (2012) who likewise showed better performance in YA compared to OA when only horizontal information was available. However, since the same study showed no age differences in sensitivity to information of vertical alignment, changes in V1 neurons would be restricted to those responsible for horizontal orientation bands.

Up to this point, a disruption in configural processing mechanisms in OA when trying to recognize stimuli with horizontal information seems the more plausible explanation. Aside the role of processing horizontal information at an early perceptual state on the one side and the later integration of configural (face-specific) information on the other, several research questions need to be addressed including the differential role of stimulus age (OAB) as well as comparing performance from tasks that primarily target perceptual skills with those focusing on face memory processes.

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Table 1

Testing for a Self-face Advantage for Sensitivity (d') and Mean Target Information Percentage

	M (SD)	*M (SD)*	*t*	*P*	*d*
Sensitivity (*d'*)					
YA (n = 23)					
HF famo vs HF self	1.38 (0.84)	2.03 (1.52)	-2.388	.030*	-0.55
NF famo vs NF self	3.31 (1.02)	3.91 (0.71)	-4,257	<.001***	-0.70
OA (n = 22)					
HF famo vs HF self	0.72 (0.51)	0.10 (1.33)	2.138	.044*	0.67
NF famo vs NF self	1.99 (0.74)	2.41 (1.43)	-1.634	.012*	-0.39
Target Information Percentage					
YA (n = 22)					
HF famo vs HF self	78.54 (12.45)	72.60 (14.97)	1.880	.074	0.43
NF famo vs NF self	68.93 (7.89)	60.53 (9.09)	4.990	<.001***	0.99
OA (n = 17)					
HF famo vs HF self	71.45 (10.27)	83.40 (11.25)	-4.010	<.001***	-1.11
NF famo vs NF self	71.18 (10.01)	71.80 (8.24)	-0.230	.824	-0.39

Note. YA = young adults; OA = older adults; HF = horizontally filtered faces; UF = unfiltered faces, famo = famous faces; *d* = Cohen's *d*.

* $p < .05$, ** $p < .01.$, *** $p < .001$.

Table 2

Summary of Correlations for Mean Target Information Percentage for both Age Groups as a Function of Filter

	HF famo	HF self	NF famo	NF self
YA				
HF famo	-			
HF self	.43*	-		
NF famo	.39	.69**	-	
NF self	.35	.45*	.58**	-
OA				
HF famo	-			
HF self	.35	-		
NF famo	.37	.43	-	
NF self	-.27	.35	.34	-

Note. YA = young adults (n = 22); OA = older adults (n = 17); HF = horizontally filtered faces; UF = unfiltered faces; famo = famous faces

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

Figure Captions

Figure 1. Samples of experimental famous face stimuli and self-faces used in the experiment. On each target trial, participants were presented with a different unfamiliar starting face (0% target information) that slowly merged into a target face (100% target information) within 20 seconds. After 10 seconds, the displayed face contained 50% target information. Faces were either presented only with horizontal facial information (HF) as a result of the selective filtering process or unfiltered (NF).

Figure 2. Young and older adults' face recognition performance (*d'*) for famous and self-faces as a function of filter (unfiltered vs filtered images). Error bars represent standard errors.

Figure 3. Young and older adults' mean target information percentage for famous and self-faces as a function of filter (unfiltered vs filtered). Error bars represent standard errors.

[1] For the purpose of this article, the term "older adults" refers to participants at around 60-80 years of age. Since not all cited authors provide detailed age ranges, some samples are given in the following. Grady, 2002: 62-75 yrs; Searcy et al., 1999: 60-80 yrs; Bäckman, 1991: 62-85 yrs; Hildebrandt et al., 2011: 65-82 yrs; Grady et al., 2000: 62-70 yrs; Habak et al., 2008: 58-72 yrs; Meinhardt-Injac et al., 2014: 65-78 yrs).

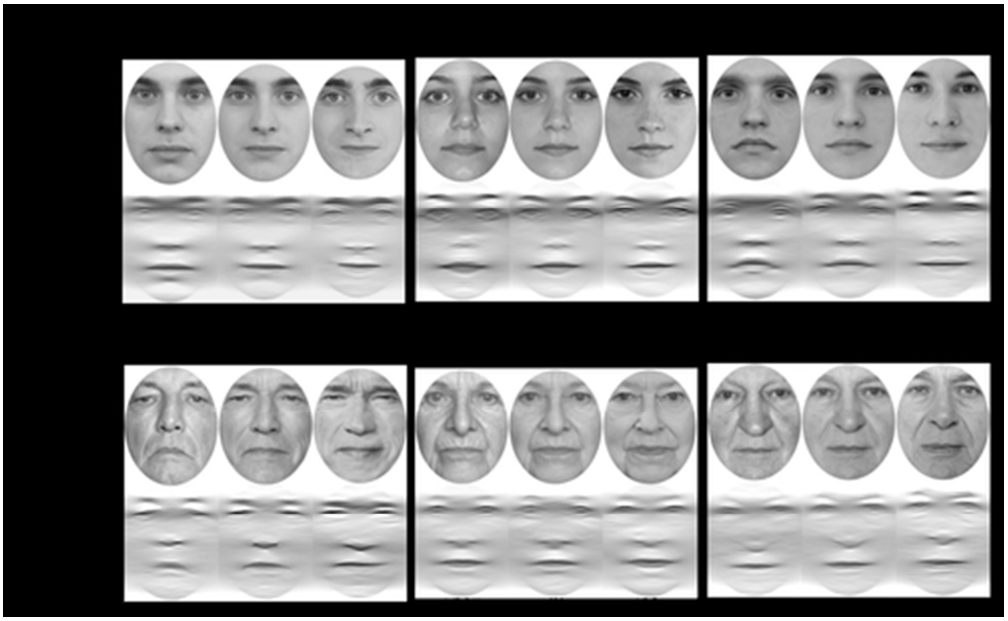

Figure 1. Samples of experimental famous face stimuli and self-faces used in the experiment. On each target trial, participants were presented with a different unfamiliar starting face (0% target information) that slowly merged into a target face (100% target information) within 20 seconds. After 10 seconds, the displayed face contained 50% target information. Faces were either presented only with horizontal facial information (HF) as a result of the selective filtering process or unfiltered (NF).

42x25mm (300 x 300 DPI)

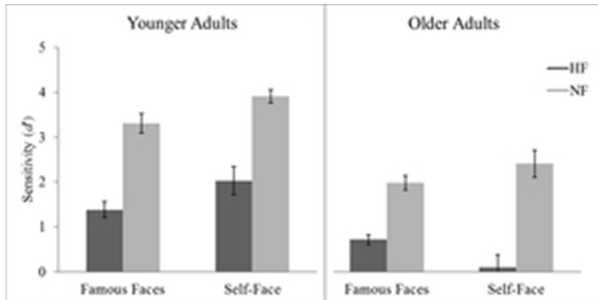

Figure 2. Young and older adults' face recognition performance (d') for famous and self-faces as a function of filter (unfiltered vs filtered images). Error bars represent standard errors.

25x12mm (300 x 300 DPI)

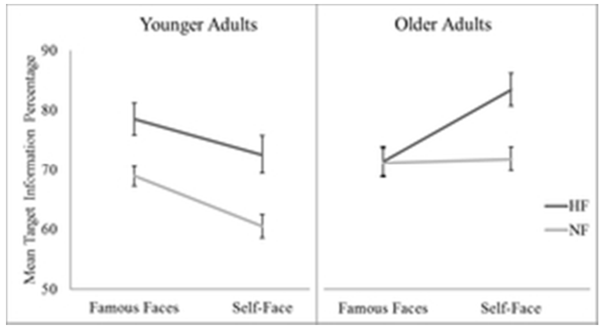

Figure 3. Young and older adults' mean target information percentage for famous and self-faces as a function of filter (unfiltered vs filtered). Error bars represent standard errors.

25x13mm (300 x 300 DPI)

B. Erklärungen

Stellungnahme zu Kriterien für publikationsbasierte Dissertationen

(1) Drei Schriften aus den letzten 5 Jahren

Obermeyer, S., Kolling, T., Schaich, A., & Knopf, M. (2012). Differences between old and young adults' ability to recognize human faces underlie processing of horizontal information. *Frontiers in Aging Neuroscience*, *4*, 3. https://doi.org/10.3389/fnagi.2012.00003

Schaich, A., Obermeyer, S., Kolling, T., & Knopf, M. (2016). An own-age bias in recognizing faces with horizontal information. *Frontiers in Aging Neuroscience*, 264. https://doi.org/10.3389/fnagi.2016.00264

Schaich, A., Obermeyer, S., Kolling, T., & Knopf, M. (2016). Age differences between younger and older adults in recognizing familiar faces: The impact of horizontal information. *Manuscript under Revision in Journal of Cognitive Psychology*.

(2) Zusammenhängendes Forschungsprogramm
Alle Publikationen bzw. Manuskripte überprüfen die gleiche Theorie im Altersvergleich

(3) Mindestens 2 Erstautorenschaften
Siehe (1)

(4) Drei Schriften zumindest zur Veröffentlichung eingereicht
Siehe (1)

(5) Mindestens 2 Schriften müssen in guten/sehr guten, i.d.R. englischsprachigen Zeitschriften mit Peer-Review eingereicht sein

Frontiers in Aging Neuroscience	Impact Factor 4.3
Journal of Cognitive Psychology	Impact Factor 1.9

(6) Eine Schrift kann in einem einschlägigen Lehrbuch […] veröffentlicht sein
entfällt

(7) Publikationen sowie Kumulus
Ca. 30seitiger Text vorhanden, der die eigenen Publikationen aus einer übergeordneten Perspektive kritisch einordnet

(8) Erklärung über die Eigenleistung

Das verwendete Stimulusmaterial entstammt diverser Datenbanken, die für Forschungstreibende frei verfügbar sind. Die Herkunft der Materialien ist in den jeweiligen Schriften entsprechend gekennzeichnet. Dr. Charles S. Dakin stellte Herrn Dr. Obermeyer und mir den Programmierungscode für die, in den Studien verwendete, Filterungsmethode zur Verfügung, welches ebenso in allen Publikationen entsprechend gekennzeichnet wurde. Sämtliche Bearbeitung von Stimulusmaterial geschah für Obermeyer et al. (2012) unter Aufsicht des Erstautors. Für die anderen beiden Publikationen oblag es mir Material anzufertigen bzw., diesen Prozess anzuleiten.

Obermeyer et al. (2012) wurde von Dr. Obermeyer erdacht, geplant und verschriftlicht. Frau Prof. Dr. Knopf, Herr. Dr. Kolling sowie meine Person lieferten Unterstützung in Designfragen und Methodenwahl. Unter Anleitung durch Herrn Obermeyer führte vor allem ich die Studie durch sowie unter meiner sowie Herrn Obermeyers Betreuung stehende Studierende. Die Datenauswertung wurde durch Herrn Obermeyer angeleitet und mit meiner Unterstützung durchgeführt. Das durch Herrn Obermeyer verfasste Manuskript wurde durch alle drei Koautoren gegengelesen bzw. überarbeitet.

Schaich et al. (2016) sowie Schaich et al. (under revision) wurden vom Erstautor sowie Zweitautor erdacht und im Austausch mit Frau Prof. Dr. Knopf sowie Herrn Dr. Kolling vor allem hinsichtlich des jeweiligen Designs konkretisiert und verfeinert. Die Durchführung erfolgte durch meine Person sowie unter meiner Anleitung. Ich analysierte die jeweiligen Daten selbstständig und verfasste beide Schriften eigenständig. Beide Arbeiten wurden in mehreren Schritten durch alle drei Koautoren gegengelesen und überarbeitet.

Datum:______________

Unterschrift:____________________

E R K L Ä R U N G

Ich erkläre hiermit, dass ich mich bisher keiner Doktorprüfung im Mathematisch-Naturwissenschaftlichen Bereich unterzogen habe.

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C. Einreichungsbestätigung des jeweiligen Journals

12-Aug-2016

Dear Mr Schaich,

Thank you for submitting your manuscript entitled "Age differences between younger and older adults in recognizing familiar faces: The impact of horizontal information" to Journal of Cognitive Psychology. It has been successfully submitted online and is with the editorial assistant awaiting further processing. Your manuscript reference ID is JCP-FA 16-139.

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D. Lebenslauf

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Ausbildung

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SS 2008 – WS 2012/13 (10 Semester) Studium der Psychologie (Diplom) an der Goethe - Universität, Frankfurt

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- Vor allem Betreuung von Bachelor- und Masterarbeiten
- WS 2015/16 Seminar „PsyBSc13 Entwicklung der Gesichtererkennung in Säuglings- und Kindesalter“

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Zwischenprüfung am 19. November 2015

Sonstiges

Wehr- / Zivildienst:	10 Monate Zivildienst bei der MSHD Caritas Sozialstation für ambulante Pflege- und Hilfsdienste, 61440 Oberursel (04.08.2003 – 31.05.2004)
Praktika / Hilfskraft:	Sechswöchiges Forschungspraktikum in der Abteilung Entwicklungspsychologie der Universität Frankfurt (01.03.2010 – 15.05.2010)
	12 Wochen klinisches Praktikum in der Gedächtnisambulanz der Universität Heidelberg (23.01.2012 – 13.04.2012)
	Juni 2010 bis Mai 2013 Technische Hilfskraft (u.a. Unterstützung bei Soft- und Hardwareproblemen, APA-Manuskriptgestaltung)
	Mitarbeit als Tutor „Empirisch-experimentelles Praktikum" bei Dr. T. Kolling, SS 2011, 2012, 2013 (u.a. allgemeine Organisation, Korrektur von Versuchsberichten, Einführung zur Datenaufbereitung und -analyse)
Sprachen	Englisch (fließend in Wort und Schrift), Französisch, Latein, Spanisch (jeweils Grundkenntnisse)
EDV-Kenntnisse	MS-Office (sehr gute Kenntnisse), SPSS (gute Kenntnisse), LISREL (Grundkenntnisse)
Freizeit:	Reisen, Kraftsport, Filme