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Affect Across Adulthood: Evidence From English, Dutch, and Spanish

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Emotions play a fundamental role in language learning, use, and processing. Words denoting positivity account for a larger part of the lexicon than words denoting negativity, and they also tend to be used more frequently, a phenomenon known as positivity bias. However, language experience changes over an individual's lifetime, making the examination of the emotion-laden lexicon an important topic not only across the life span but also across languages. Furthermore, existing theories predict a range of different age-related trajectories in processing valenced words. The present study pits all of these predictions against written productions (Facebook status updates from over 20,000 users) and behavioral data from three publicly available megastudies on different languages, namely English, Dutch, and Spanish, across adulthood. The production data demonstrated an increase in positive word types and tokens with advancing age. In terms of comprehension, the results showed a uniform and consistent effect of valence across languages and cohorts based on data from a visual word recognition task. The difference in reaction times to very positive and very negative words declined with age, with responses to positive words slowing down more strongly with age than responses to negative words. We argue that the results stem from lifelong learning and emotion regulation: Advancing age is accompanied by an increased type frequency of positive words in language production, which is mirrored as a discrimination penalty in comprehension. To our knowledge, this is the first study to simultaneously target both language production and comprehension across adulthood and in a cross-linguistic perspective.

Keywords: aging, valence, emotion, language production, language comprehension

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Emotions leave a noticeable footprint on language learning, use, and processing (for reviews, see, e.g., Borghi et al., 2017; Citron, 2012; Ochsner, 2000). To give a few examples, emotionally loaded—that is, positive or negative—words (e.g., *vacation*, *illness*) tend to be learned better and recognized or produced faster than their neutral counterparts (e.g., *table*, *street*; see Kuperman, Estes, Brysbaert, & Warriner, 2014 and references therein). Also, psychological positivity or valence is a primary vehicle of learning abstract words; that is, words that do not have tangible referents in the material world are learned and recognized faster if they have strongly valenced meanings (Kousta, Vigliocco, Vinson, Andrews, & Campo, 2011; Ponari, Norbury, & Vigliocco, 2018; Vigliocco, Ponari, & Norbury, 2018).

An influential view explains the substantial impact of affect on language by arguing that subjective valence of a stimulus engages one of two motivational subsystems: one geared toward objects that facilitate survival and another geared toward responding to threat and danger (e.g., Bradley & Lang, 2000; Wurm, 2007). Yet the affective biases, the relative need for survival and avoidance of danger; emotion regulation; and language experience change over an individual's lifetime. The dynamic nature of human emotion and cognition suggests that age modulates how language reflects affect and how affect is perceived through language. As we discuss below, the current state of knowledge about the nature of the interaction between aging, affect, and language use is incomplete. This article harnesses large-scale collections of behavioral data across adulthood to examine the distribution of affect in language

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production over age and its consequences for written word recognition. Below, we identify four empirical findings that are both robust in the literature and pertinent to the topic of our interest and a broader context. We then briefly summarize our (nonexhaustive) examination of relevant theoretical accounts, formulate their predictions for production and comprehension of affective lexicon over age, and outline how our studies test these predictions. In short, this study examines the production and comprehension of affective words in adulthood.

Key Empirical Findings

The question of aging and affective language can be studied only in a broader context of the interaction between age and language in general (see Burke & Shafto, 2008; Shafto & Tyler, 2014 for discussion). Four relevant findings appear to have strong empirical support in the current literature and serve as explicanda for existing theoretical accounts and our own theorizing below. Thus, (a) vocabulary knowledge displays a steady growth across adulthood (Brysbaert, Stevens, Mandera, & Keuleers, 2016; Hartshorne & Germine, 2015; Keuleers, Stevens, Mandera, & Brysbaert, 2015; Ramscar, Hendrix, Shaoul, Milin, & Baayen, 2014; Verhaeghen, 2003). Also, (b) older individuals display longer response latencies in tasks related to language production and comprehension (see Ratcliff, Thapar, Gomez, & McKoon, 2004; Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006; Salthouse, 1996) and lower reading speed (see Kemper & Liu, 2007; Rayner et al., 2006; Solan, Feldman, & Tujak, 1995; Whitford & Titone, 2017). A third finding (c) is that even the structure of lexicon is shaped by emotion, as evidenced by the cross-linguistic positivity bias. There are more distinctly positive words (i.e., words scoring above the middle of the valence scale) in vocabularies of multiple languages, and these words are used more often than negative ones (Boucher & Osgood, 1969; Dodds et al., 2015; Warriner & Kuperman, 2015).

Finally, (d) aging is robustly associated with a changes in cognitive selectivity, specifically an increasing preference for positive rather than negative stimuli (see Carstensen & DeLiema, 2018; Reed, Chan, & Mikels, 2014 for an overview). This effect has been found in a wide array of different cognitive domains including attention, working memory, autobiographical memory, and decision-making, among others (see Carstensen, 2006; Carstensen & Turk-Charles, 1994; Mather & Carstensen, 2005; Reed et al., 2014; Ruffman, Henry, Livingstone, & Phillips, 2008; Samanez-Larkin & Knutson, 2015). As reviewed in Mather and Carstensen (2005), older individuals experience or express fewer negative emotions. They tend to have more positive memories about their past in autobiographical memory tasks; in memory tasks, they remember positive verbal or pictorial stimuli better and show a higher rate of forgetting the negative ones; and in attention tasks, they focus on positive stimuli more than their younger counterparts. In terms of emotion-recognition ability, however, recent evidence suggests that the peak performance of this ability remains fairly stable between ages 40 and 60 years (Hartshorne & Germine, 2015).

Theoretical Accounts

To our knowledge, no single relevant account has targeted both language production and comprehension over the life span, nor have findings (a)−(d) been considered jointly. Our review below focuses then on formulating predictions that existing accounts would generate had they had findings (a)−(d) as an input; we also mention theoretical proposals that are by design confined to only some facets of the interaction between language, aging, and affect.

The "emotion regulation" account proposes that the increased positivity in aging individuals (finding c) is due to the accumulating improvement in control over emotions, which parallels biological maturation (see reviews by Charles & Carstensen, 2007; Urry, 2016). Older individuals are less prone to feeling negative emotions, engage in more efficient coping strategies in the face of distress, and are more strategic in selecting partners and experiences that lead to positive emotional states. Under this account, a combination of findings (a), (c), and (d) leads to a prediction that the growing vocabulary of older individuals will contain an ever-increasing proportion of positive words, leading to age-related amplification of positivity bias. To our knowledge, this prediction has not been tested yet; our Study 1 fills this lacuna.

As will become important for Studies 1 and 2 below, the amplification of the positivity bias predicted under the "emotion regulation" account may take different forms. A useful distinction for operationalizing this change is one between word tokens (the number of times a given word occurs in language production of an individual or a group) and word types (the number of distinct words in one's vocabulary). Metaphorically speaking, word types represent the number of different tools in one's linguistic toolkit, and their tokens represent how often each tool is used. As observed in Warriner and Kuperman (2015) in a study of generic (nonage specific) corpus data, the positivity bias emerges both in the type frequency (there are more positive words than negative ones) and token frequency (positive words are used more often). If the preference for positive stimuli in older participants in memory and attention tasks (e.g., Carstensen & Turk-Charles, 1994; Kalenzaga, Lamidey, Ergis, Clarys, & Piolino, 2016; Reed & Carstensen, 2012) does translate into an age-driven increase in positivity bias, it may emerge in type frequency (older individuals use a larger number of distinct positive words), in token frequency (older individuals use an average positive word more often), or both. We demonstrate below that different scenarios for the change in positivity bias in language production (showing in type frequency only, token frequency only, or both) give rise to radically different predictions regarding recognition of words' connotating affect; these are examined in Study 2.

A second account that we consider can be labeled a "use it or lose it" account (see Aschwanden et al., 2019; Hampshire, Sandrone, & Hellyer, 2019; Shimamura, Berry, Mangels, Rusting, & Jurica, 1995). The prime example of this account is the very well-documented frequency effect (see Brysbaert et al., 2011; Brysbaert, Mandera, & Keuleers, 2018 for overview): Words that occur more frequently in language production are easier (faster) to recognize during language comprehension. Conversely, a decrease in the use of a word would be paralleled by a greater effort of recognizing that word. Importantly, this account predicts that language comprehension behavior will closely mirror changes in the frequency distribution of emotion-laden words. If aging comes with a more frequent use of positive words, we expect to observe a *faster* recognition of positive rather than neutral or especially negative words. This prediction for language comprehension is expected to hold both for an increase in positive word types or tokens and regardless of the reasons for that increase (e.g., due to a better emotion regulation or due to a prevalence of positive experiences in the older adults' environments).

A third usage-based account, which we refer to as "lifelong learning," generates a different set of predictions. This account proposes that—as a result of knowledge accumulation over time—older individuals have encountered a larger number of words and that, on average, they have encountered each word more often (see Baayen, Tomaschek, Gahl, & Ramscar, 2017; Ramscar et al., 2014). Because vocabulary size increases with age (finding a), discrimination among words becomes more difficult, resulting in increased reaction times (RTs) in a number of lexical tasks (see, e.g., Milin, Feldman, Ramscar, Hendrix, & Baayen, 2017; Ramscar, Dye, Blevins, & Baayen, 2018; Ramscar, Dye, & McCauley, 2013; Ramscar, Hendrix, Love, & Baayen, 2013; Ramscar et al., 2014) and in other cognitive tasks such as decision-making (see Blanco et al., 2016). Thus, under this account, no cognitive deficit is required to explain the observed slowdown in recognition times (finding b; see Ramscar, Dye, & McCauley, 2013; Ramscar, Hendrix, et al., 2013; Ramscar et al., 2014).

The lifelong learning account also has implications for the comprehension of affective words. Specifically, the increase in the number of distinct positive word types with age would lead to a slowdown in the recognition of positive words relative to negative ones; see above. Under this account, the ease of recognizing a word is proportional to the ease of discriminating this word from all other competitors; this ease is in turn proportional to how informative the cues associated with this word are (Ramscar, Hendrix, et al., 2013, 2014; Rescorla & Wagner, 1972; Rescorla, 1988). An increase in the number of positive word types with age is predicted to make a word's positive connotation a less informative cue. A similar proposal and empirical evidence that positive words are more numerous, more alike one another, and less informative than negative words are also given in Garcia, Garas, and Schweitzer (2012) and in Alves, Koch, and Unkelbach (2017). The implication of these findings is that if the lexical space for positive words becomes more crowded with age, it is more difficult to tell positive words apart from each other, predicting slower responses to positive words. This is opposite to the prediction under the "use it or lose it" account. We note that our treatment of the "lifelong learning" account assumes that affective connotations (e.g., positivity or negativity) can serve as cues to the word's meaning; we justify this assumption in the General Discussion.

Several additional accounts are relevant for some but not all findings (a−d) and only generate predictions for language comprehension; we consider them below. One common explanation of the slowdown of lexical processing in older individuals is cognitive decline that comes with age. A number of studies on age-related cognitive functioning suggest that aging can compromise some cognitive abilities related to fluid intelligence—for example, attention, executive control, and working memory (Bopp & Verhaeghen, 2005; Kausler, 1991; Salthouse, 1991; but see Verhaeghen, 2011)—whereas abilities associated with crystallized intelligence—for example, domain-related knowledge and experience—remain unaffected (Verhaeghen, 2003). These deficits are argued to lead to more effortful lexical processing, while lexical knowledge is assumed to remain intact (see Burke & MacKay, 1997; Thornton & Light, 2006, among others); see finding (b). While this "cognitive decline" account can explain changes in the overall language comprehension behavior, to our knowledge, it makes no specific prediction that the decline is particularly pronounced for, say, positive versus negative words. Furthermore, the account makes no predictions for age-driven changes in the production of affective language or the structure of the affective lexicon.

Moreover, a proposal exists that with age, the engagement of motivational systems associating valence with survival or danger weakens (Al-Shawaf, Conroy-Beam, Asao, & Buss, 2015; LeDoux, 2012). We label this a "flattening affect" proposal. If this is the case, then differences in response latencies to positive and negative words should become smaller over time because the affective differences underlying this behavioral contrast dwindle.

Finally, there is a possibility of a null effect of emotional information on language comprehension; that is, affect and its implications for production patterns have no independent influence on age-related changes in language production or comprehension. Indeed, some literature advocates a view that aging does not lead to either flattening nor amplification of the role that affect plays in memory tasks (see, e.g., Comblain, D'Argembeau, Van der Linden, & Aldenhoff, 2004; Denburg, Buchanan, Tranel, & Adolphs, 2003; Eich & Castel, 2016; Leshikar, Dulas, & Duarte, 2015).

The Present Study

Our literature review above identified predictions regarding different facets of production and comprehension patterns for emotion-laden words. These predictions are often conflicting, and no account is designed to paint a full picture of how age effects on production propagate to the distribution of affective language and shape comprehension behavior. We test these predictions in two studies and offer rich and novel empirical material for further theorizing on this topic.

Study 1 reports analyses of the large data set of written productions and answers the question of whether and how the positivity bias presents itself in naturally occurring free-form language over five decades of age. While extensive, the current literature on the topic leaves some questions unanswered. First, most prior research has compared a group of older participants with one control group of younger individuals on a given task (Carstensen & Turk-Charles, 1994; Isaacowitz, Charles, & Carstensen, 2000; Leclerc & Kensinger, 2011; Reed et al., 2014; Ruffman et al., 2008; Scheibe & Carstensen, 2010). This experimental design does not shed light on whether the change in affect is gradually developing across the timeline of aging or is confined to a certain age group. Second, most tasks involving language exercise tight experimental control and thus elicit verbal productions in response to highly constrained sets of stimuli. It is unclear whether and to what degree the patterns elicited experimentally generalize over natural language behavior, produced under conditions immune to a reactivity bias. Third, much of prior work has used relatively small samples of individuals, often using university students as younger controls (see Verhaeghen, 2011 for discussion). To address these gaps, our Study 1 investigates the structure of the affective lexicon in over 20,000 adults from 24 to 85 years of age based on their status updates on the social networking website Facebook. We analyze these texts as ecologically valid linguistic indicators of the distribution of affect over adulthood. While affective computing in general has received wide attention in machine learning (see, e.g., Calvo & D'Mello, 2010; Hussain & Cambria, 2018; Poria, Cambria, Bajpai, & Hussain, 2017), to the best of our knowledge, Study 1 is the first systematic inquiry of age-related effects on the emotional content in natural written language. Yet for studies investigating the relationship between language and cognition, naturally occurring data are critical as language is inherently societal and grounded in time and place. Indeed, natural language productions, including an individual's social media behavior, have been fruitfully used to predict a number of traits such as depression (Eichstaedt et al., 2018), age and gender (Sap et al., 2014), personality (Guntuku et al., 2017), and stress (Guntuku, Buffone, Jaidka, Eichstaedt, & Ungar, 2019). For a similar big-data approach addressing other dimensions of language and age, see Schwartz et al. (2013).

Adjudicating between possible instantiations of the Age × Affect interaction in language comprehension (listed above) requires a high-power empirical examination. Our Study 2 addresses this by examining patterns of responses to words varying in their psychological positivity in three languages (Dutch, English, and Spanish) and in participants spanning four decades of adulthood (from 24 to over 60). The empirical sources are three megastudies reporting lexical decision accuracy and RTs for thousands of participants. Given the discrepancy in availability of valence norms across the three languages, we present the analysis in two parts. In Study 2a, a descriptive analysis of the data originating from the three languages is presented, and in 2b, a more detailed regression analysis of the English data is provided.

Additionally, Study 2 pits these data against a wealth of theoretical accounts of cognitive and emotional change to identify those accounts that are both compatible with distributional patterns in data production and find cross-linguistic support in comprehension data from a visual lexical-decision task. Evidently, theorizing based on concurrent consideration of language production and comprehension data is only meaningful under an assumption that preferences in one of these communicative functions are relevant and material for the other. Indeed, multiple theoretical accounts—while varying in detail—advocate this linking hypothesis; see MacDonald (2013), Pickering and Garrod (2013), and Ramscar and Baayen (2013) as topic papers as well as the commentaries.

Put in a simplified way, distributional biases in favor of some linguistic units or structure over others arise as a result of multiple, often conflicting, physiological, cognitive, and communicative demands for efficiency coming from both speakers and listeners (Ferreira, 2008; Jaeger & Tily, 2011). Language production both reflects these distributional biases and contributes to them. Yet speakers are also comprehenders, and as much research demonstrates (e.g., Hale, 2006; Levy, 2008), they make predictions about upcoming forms that are attuned to probabilities of those forms in the input. The structures that speakers preferentially produce become more probable in the language, and in turn, those structures become more expected and easier to process during comprehension. Theories differ in their proposed mechanisms that enable the cross-talk between production and comprehension, yet they generally agree that distributional preferences expressed in production are learned by comprehenders and thus inform comprehension behavior. For our purposes, this linking hypothesis suggests that a preference for, say, positive words in naturally occurring speech or writing of older individuals will translate into an increased expectation of positive words by comprehenders and will change how informative a word's positive connotation is as a cue to word recognition (e.g., Ramscar & Baayen, 2013). In the General Discussion, we will elaborate on the implications of our joint consideration of language production and comprehension for the theoretical accounts linking these two cognitive abilities.

In sum, we pursue three goals. One is to conduct a novel investigation of whether age has an effect on preferential use of negative or positive words and how this effect is expressed in the frequency distributions of those valenced words (Study 1). This study contributes large-scale and ecologically valid observational evidence to a field that has at times been constrained to underpowered experimentation. Second, we investigate responses to valenced words in a lexical-decision task across languages and age groups (Study 2), with the goal of pitting these data against a wealth of theoretical accounts of cognitive and emotional change and identifying those accounts that find cross-linguistic support. Our third and final goal is to suggest at least some mechanisms that tie together age-driven changes in both language production and comprehension. We elaborate on this topic in the General Discussion.

Study 1

The goal of this study was to determine age-related changes in frequency-trajectories of the affective lexicon across adulthood. We present an analysis based on naturally occurring written texts, that is, Facebook status updates in English. We focused on the type and token frequency distributions associated with the affective lexicon in order to test whether and how positivity bias presents itself (Dodds et al., 2015; Warriner & Kuperman, 2015). The analysis allowed us to test whether the change in affect over age was gradual or confined to a specific age group.

Method

The data consisted of 12,026,030 status updates posted on Facebook by 115,112 users as part of the myPersonality Facebook application (see Kosinski, Stillwell, & Graepel, 2013 for details). The secondary use of these data was approved by the McMaster Research Ethics Board (certificate: 2018–089). We only included the status updates from those users who self-reported to be between 24 and 85 years of age and reside either in the United States, Canada, or the United Kingdom. These restrictions allowed us to obtain comparable results between the different studies presented in this article; see Study 2. The final data set contained status updates from 22,288 users.

Several preprocessing steps were taken to prepare the status updates for analysis and were carried out in R, Version 3.6.1 (R Core Team, 2019). As a preprocessing step, the status updates were tokenized, parsed, and lemmatized using UDPipe as implemented in the R package udpipe, Version 0.8.2 (Straka & Straková, 2017). After that, the affective lexicon was established by matching the lemmata of the status updates to their corresponding English valence norms (N = 13,915) collected in the previous megastudy by Warriner, Kuperman, and Brysbaert (2013). Furthermore, all words that lacked the valence information were removed. Finally, in order to keep the different data sets comparable in terms of age, the users were divided into five age groups: 24–29, 30–39, 40–49, 50–59, and 60+. These same age groups also were used in Study 2. The summary information of the variables associated with the users and the lexical properties of the status updates is provided in Table 1.

Results

To test for the presence of the positivity bias based on the Facebook status update data, we calculated the average valence score for each user based on the affective words used in their status updates. First, word-based valence ratings were averaged for each sentence. Second, the average valence rating of a given status update was calculated by averaging over the sentence-level ratings in a given update. Third, the valence rating of the status updates was averaged for each user. We will refer to this final measure as the average user valence score.

The average user valence scores were then compared to the midpoint of the valence scale, that is, a rating of 5, to test for the presence of a positivity bias reported in non-age-specific data sets (see Warriner & Kuperman, 2015) and reference therein. Valence scores averaged per user across the age groups were uniformly greater than the midpoint of the valence scale (see Table 2). Thus, the positivity bias is found in the Facebook status updates, similar to many other text types (see Dodds et al., 2015).

Additionally, the positivity bias strengthened with advancing age as the average valence score of the users was positively correlated with age: $r(22{,}286) = .17$, $p \leq .001$, 95% CI [.16, .18].[1] It is worth pointing out that the magnitude of the correlation aligned with the experimental results reported by Augustine, Mehl, and Larsen (2011) in Study 2 for recordings of conversational English.

In order to identify whether the positivity bias emerged specifically in type frequency, we calculated the number of word types produced in a given age group and then averaged the valence ratings associated with the types. The distributional information of the valence ratings among the word types is given in Table 3.

The summary information indicated that increasingly more positive word types were produced with advancing age. A linear regression model was fitted to the data, and the results confirmed that the main effect of age group was a statistically significant predictor of the valence rating: $F(4, 58{,}441) = 19.50$, $p \leq .001$. Furthermore, the age-related difference in the valence ratings emerged as statistically significant between the youngest adult group and the age group from 50 to 59, $b = 0.06$, $t(58{,}441) = 3.37$, $p < .001$, 95% CI [0.02, 0.09], and the youngest and the age group 60+, $b = 0.14$, $t(58{,}441) = 7.83$, $p < .001$, [0.11, 0.18]. To use our metaphor, as people age, they consistently use an increasing number of distinct words as tools recruited to convey a positive meaning. The change is gradual and not confined to a specific age group across adulthood. However, it is possible that this age-related positivity bias as reflected in word types arose due to a confound of how type frequency in general is distributed in language. To rule out this possibility, we provide two additional analyses.

Table 1
Summary Information of the Variables in the Status Update Data Set

Age group	Users N	Status updates N	Words N	Word types N	Length of status update M	SD
24−29	9,475	1,106,362	7,850,535	13,170	7.1	6.18
30−39	6,349	635,842	5,043,796	12,875	7.93	6.83
40−49	4,033	384,078	3,200,399	12,520	8.33	7.18
50−59	1,885	140,301	1,236,494	11,296	8.81	7.51
60+	546	36,571	318,692	8,585	8.71	7.53

Table 2
Distribution of the Average Valence Scores of the Users in Each Age Group

	Valence		*t* test		
Age group	*M*	*SD*	*t*	*df*	*p*
24−29	5.93	0.19	473.3	9,474	<.001
30−39	5.98	0.2	387.54	6,348	<.001
40−49	6.01	0.22	293.34	4,032	<.001
50−59	6.04	0.24	185.93	1,884	<.001
60+	6.03	0.3	79.98	545	<.001

Note. The results of a Welch's one-sample upper-tailed t test comparing the average valence score of the users in a given age to the midpoint of the valence scale.

The first potential source of the confound concerns the relation between type and token frequency. The youngest adult group produced substantially more word tokens and consequently more word types in our data set than the oldest adult group—see the summary information in Tables 1 and 3. This imbalance might skew the distribution of frequency data because of the well-attested codependency of token and type frequency (see, e.g., Baayen, 2001). To rule out this confound, we reanalyzed the data while holding the number of word types constant across the age groups. The increased number of positive word types with advancing age was supported by this reanalysis, leading us to conclude that this finding is not artifactual (see online Supplemental Materials S1 for the analysis).

The second potential confound concerns the relation between type frequency and lexical growth. It is conceivable that the increased type frequency of positive words emerged solely due to the increasing size of the lexicon and that it is not age related. If this is the case, we should observe a relative increase in type frequency of positive words in larger corpora compared to smaller ones. To rule out this possibility, we extracted documents of the American and British English subsections of the 1.9-billion-token Global Web-Based English corpus. Written productions in this corpus are not specific to any age. We incrementally increased the size of the samples we extracted from this corpus and examined the positivity bias relative to the sample size. The results demonstrated that the proportion of positive word types in the sample

[1] There are several ways of calculating the average valence score for a given user. However, the manner of calculating the score did not alter the trend when it was calculated simply over all the affective words produced by a given user, $r(22286) = .15$, $p \leq .001$, 95% CI [.13, .16], or when the valence score was calculated based on individual status updates of a given user excluding the sentence-level averaging, $r(22286) = .16$, $p \leq .001$, [.15, .17].

Table 3
Information of the Valence Rating Across the Word Types and the Age Groups in the Status Update Data

	Valence					
Age group	*M*	*SD*	*Mdn*	Lower quartile	Upper quartile	Type frequency *N*
24−29	5.07	1.28	5.21	4.25	5.95	13,170
30−39	5.08	1.28	5.21	4.25	5.95	12,875
40−49	5.09	1.29	5.23	4.26	5.95	12,520
50−59	5.13	1.3	5.26	4.32	6	11,296
60+	5.21	1.32	5.35	4.43	6.13	8,585

decreased when the size of the sample increased. This runs counter to our observations of a stronger positivity bias in written productions of older individuals. We conclude that the mere growth in vocabulary that comes with age cannot explain away the stronger positivity bias in aging language users (see online Supplemental Materials S2 for the analysis).

As our next step, we proceeded to identify token frequency-trajectories in the affective lexicon across adulthood. To this end, we first set three pairs of thresholds to specify positive and negative word groups: the median split of the valence distribution, thus covering 100% of available words (the ties were assigned to the lower half); the top and bottom 25% of the valence distribution, thus covering 50% of available words; and the top and bottom 15% (covering 30%). This enabled us to study the effect of age on mildly valenced words (e.g., the median split) and extremely valenced ones (the extreme 30%). We will refer to them as lexical coverage groups. Second, the token frequency was calculated for positive and negative words for each lexical coverage group; the counts were based on the lemmata used in the status updates separately for each age group. To account for the differences in sample sizes across groups, the frequencies of the lemmata were normalized per 100,000 and log transformed (base 2) with a constant of 1 added to the values to move away from zero. Third, we estimated a token frequency-trajectory of the positive and negative words by calculating the median of their log-normalized token frequencies in a given age and lexical coverage group. These trajectories are visualized in Figure 1.

The shape of the token frequency-trajectories indicated that the positive words were used more often than the negative ones with advancing age, and this monotonic age-related effect was effectively stable across the age groups and the lexical coverage groups. Additionally, a marked increase in the frequency of use of the affective lexicon occurred when comparing the token frequency-trajectories between the youngest and the oldest adult groups. However, the strength of the age-related modulation of the valence effect varied depending on the lexical coverage group. This modulation became larger when the lexical coverage group shifted toward the extremes of the valence distribution; the largest modulation was observed in the 30% lexical coverage group. To confirm that this type of modulation of the valence effect was not just limited to the median but also characterized the token frequency distribution as a whole, the token frequency distribution for the positive words in the youngest (24–29) and the oldest (60+) adult group is visualized in Figure 2.

The density plots showed a clear pattern of increased use of the positive word tokens in the oldest adult group compared to the youngest adults. We used the permutation test of equality between two density distributions as implemented in the R package sm, Version 2.2.5.6, to formally test whether the densities differed (Bowman & Azzalini, 1997). All the estimated *p* values were less than .001, indicating that the density distributions of the token

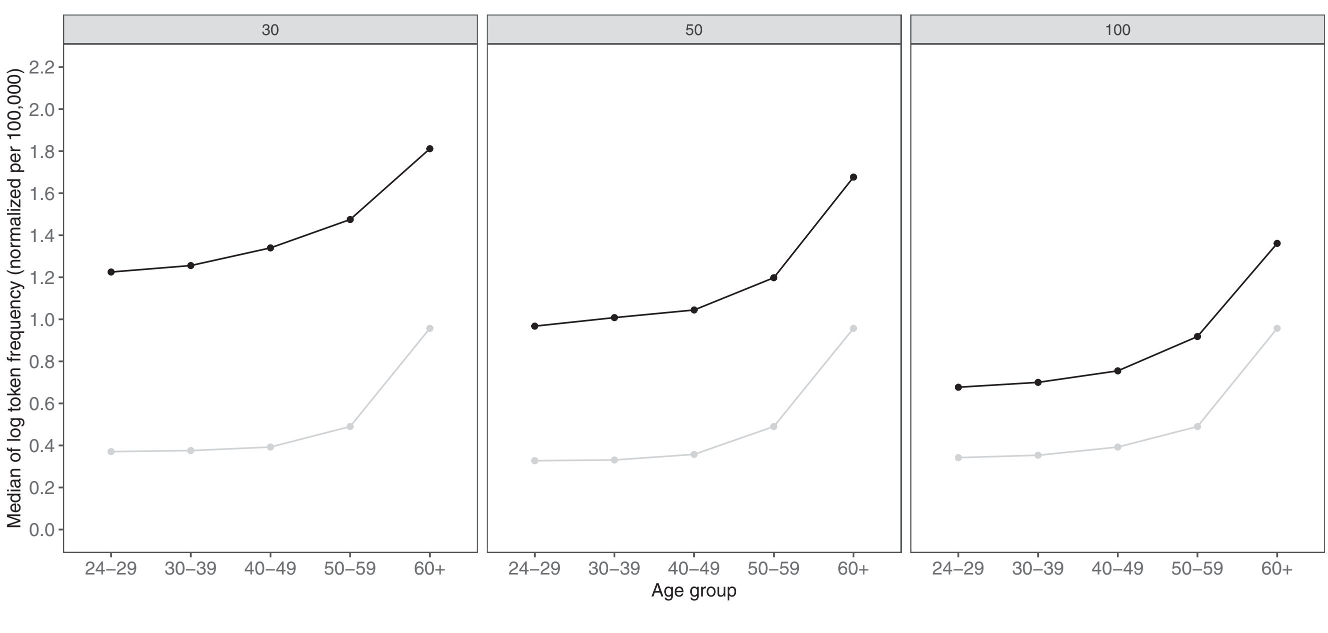

Figure 1. Median frequency-trajectories for the positive and negative words across the age groups and for the 30% (left), 50% (middle), and 100% (right) lexical coverage.

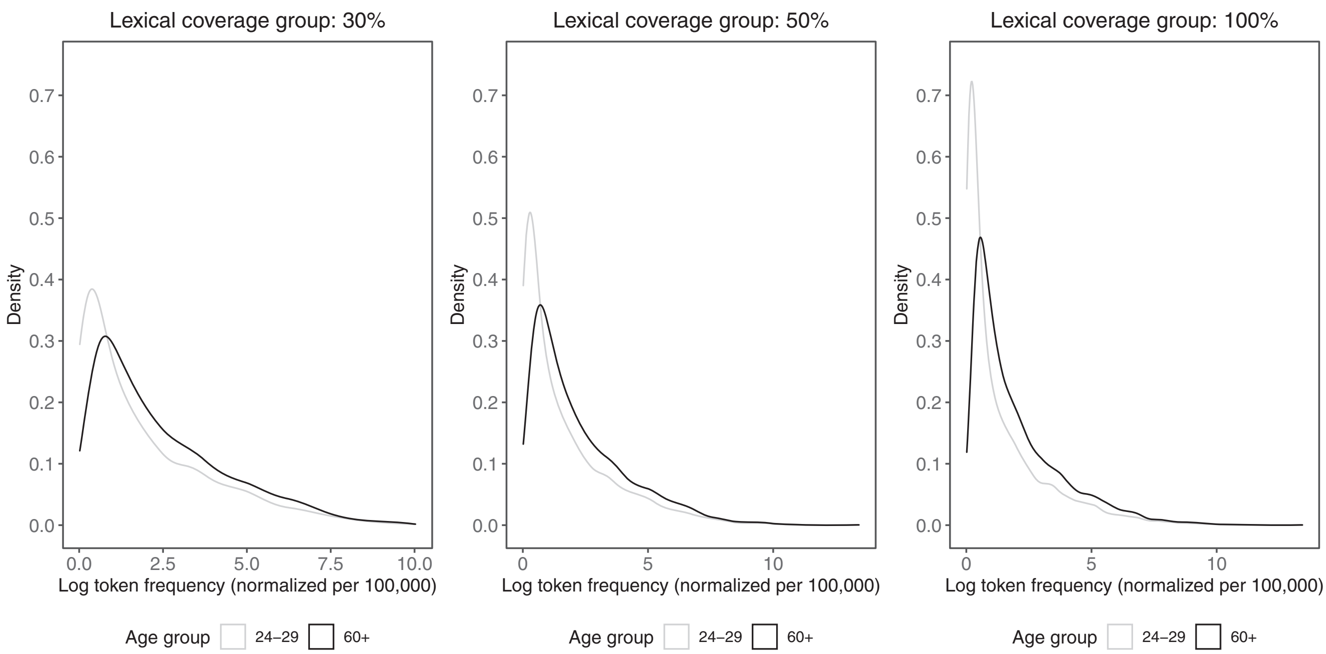

Figure 2. Distribution of the log-normalized token frequency for the positive words in the youngest and the oldest adult groups across the three lexical coverage groups.

frequencies were not equal between the youngest and the oldest adult groups across the lexical coverage groups for the positive words, even after correcting for multiple comparisons. In sum, the results demonstrated that not only did the token frequency-trajectory of the positive words become more pronounced with advancing age, but the distribution as a whole also shifted toward the increased use of the positive words.

Discussion

In Study 1, we investigated the use of the affective lexicon across adulthood in a large data set of naturally occurring productions, namely Facebook status updates. The analysis specifically focused on the token and type frequency distributions associated with the affective lexicon. Type frequency captures the diversity of affective words used, whereas token frequency informs us about how often affective words are used. The results of the production data support the "emotion regulation" account. The analysis demonstrated that the positivity bias manifested itself in *both* token and type frequencies. Not only did the Facebook status updates consist of more positively valenced lexical types, but positive words also were used more frequently with advancing age. While the frequency of use of both the positive and negative words increased as age advanced, the differences in frequency distributions of positive words became more pronounced in the oldest adult group compared to the youngest adults. This trend is compatible with a notion that age correlates with better emotion regulation. Another partial contributor may be emotional contagion, a tendency of social media users to generate more positive posts if they see more positive posts in their newsfeed (Kramer, Guillory, & Hancock, 2014).[2] If social media users predominantly communicate with peers of their own age, then emotional contagion may amplify effects of emotion regulation. A tendency toward positivity in some individuals, reflected in their written texts, may induce a similar affective preference in their age group.

Together, these results replicate and support the positivity bias reported in previous studies (Boucher & Osgood, 1969; Dodds et al., 2015; Warriner & Kuperman, 2015) and add important evidence on the specific role of age. The observed trend toward positivity is not a domain of old age, nor is it a finding limited to tightly controlled experiments, but rather a gradual process that characterizes the entire adulthood.

Finally, the observed strengthening of the positivity bias in linguistic productions with advancing age has important implications for models of language comprehension. Were we to find an increasing positivity bias in word types or word tokens only, some of the theoretical possibilities for the age-driven change in comprehension of affective words would have been ruled out. The present language production data supports the possibility of at least two frequency-related accounts of changes in word recognition, namely the "use it or lose it" account and "lifelong learning" (see introduction). Study 2 below examines predictions of these and additional accounts against cross-linguistic data sets of word recognition RTs.

Study 2

Study 2 presents two analyses of word recognition data. In Study 2a, we investigated the role of aging and affect cross-linguistically by analyzing RTs in a visual lexical-decision task from English, Dutch, and Spanish. This allowed us to compare the predictions from the different existing theoretical accounts and to

[2] We thank an anonymous reviewer for bringing this to our attention.

validate the results in three high-power data sets. As the results of Study 1 showed that both the type and token frequencies of words with positive connotation increased with advancing age, we focused on the relative difference between recognition of the positive and the negative words in Study 2a. This allowed us to specifically test the following hypotheses in a cross-linguistic setting: (a) “use it or lose it”: relatively faster RTs to positive than negative words, (b) “lifelong learning” account: a relatively stronger reduction in RTs to positive than to negative words, (c) engagement of motivational systems: reduction in RTs to both positive and negative words, and (d) preserved emotional memory: no age-related change in RTs to either negative or positive words. For a detailed exposition of these accounts, see the introduction. Study 2b zooms in on English and addresses in depth several potential confounds that can explain away some findings of Study 2a.

Study 2a

Method. The data analyzed here came from three publicly available megastudies of visual lexical decision in English (for accuracy, see Brysbaert, Mandera, McCormick, & Keuleers, 2019; for RTs, see Mandera, Keuleers, & Brysbaert, 2019), Dutch (for accuracy, see Keuleers et al., 2015; for RTs, see Brysbaert, Keuleers, & Mandera, 2019), and Spanish (Aguasvivas et al., 2018). The English data set was restricted to native speakers of English who resided either in the United Kingdom or the United States. The English data set consisted of 61,858 words in total and represented approximately 650,000 sessions (in each session, a participant responded to 100 stimuli). Similarly, the Dutch data set was restricted to native speakers of Dutch or Flemish and contained data on 54,319 words and approximately 450,000 sessions. While the Spanish data set covered data from approximately 169,000 sessions across Spanish-speaking countries, we restricted the data set to speakers of Peninsular Spanish, approximately 49% of the data. This data set included 45,389 words. Finally, the analysis presented here only included the RTs for correct responses.

The studies were conducted online using crowdsourcing. All three megastudies made use of the same visual lexical-decision task in which participants were asked to indicate whether they knew the stimulus or not. Both accuracy and RT data were collected along with basic demographic information. Each session consisted of 100 stimuli with the following approximate word-to-nonword ratio: 70/30 in English, 67/33 in Dutch, and 70/30 in Spanish. The RTs of the English and Dutch data sets have been compared to the results reported in previous studies. For example, Mandera et al. (2019) demonstrated that these new norms were highly comparable to the RTs in the English Lexicon Project with a correlation of .75 for the shared words. Similarly, Brysbaert, Mandera, et al. (2019) showed that the words shared between these new Dutch norms and the norms in the Dutch Lexicon Project (Keuleers, Diependaele, & Brysbaert, 2010) were strongly correlated (.7). Thus, these studies have demonstrated that the new response norms are of high quality, while simultaneously representing a far more diverse population.

In order to investigate the role of affect on word recognition across adulthood, the words covered in the three megastudies of visual lexical decision were matched with the valence norms collected in the previous megastudies for English (Warriner et al., 2013), Dutch (Moors et al., 2013), and Spanish (Stadthagen-Gonzalez, Imbault, Sánchez, & Brysbaert, 2017). To avoid undesirable variability in the levels of lexical knowledge across age, we only considered those words that were very well-known. We used the average accuracy as a proxy for lexical knowledge with a cutoff point of 90% correct in each age group (see Lemhöfer & Broersma, 2012; Stubbe, 2012 for justification). For valence, we used the same three lexical coverage (30%, 50%, and 100% of the words) groups, enabling us to study the effect of age on mildly valenced words and extremely valenced ones. Finally, the five age groups were considered in this study as in Study 1. The language-specific summary of the data is provided in Table 4.

We tracked the relative changes in RTs associated with valence across adulthood in each of the languages in the following manner. First, we calculated the average RTs weighted by the number of observations in each age group; this was done separately for the positive and negative words in each lexical coverage group. Second, this averaging was carried out separately for each of the languages. Finally, to estimate a relative change related to valence, we calculated ΔRT (average negative RT − average positive RT) in each data set defined by language, age group, and lexical coverage group.

Results. Figure 3 (top row panels) visualizes the age- and valence-related trajectories of the ΔRTs across the three languages

Table 4
Language-Specific Summary of the Valence Data for Each Language in the Three Different Lexical Coverage Groups

Language	Lexical coverage	Word valence		Valence rating				Reaction time (ms)				Number of observations			
				Negative		Positive		Negative		Positive		Negative		Positive	
		Negative *N*	Positive *N*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Dutch	30%	621	642	2.24	0.32	5.53	0.36	1,062.05	119.78	1,028.09	104.94	73.62	12.74	70.68	12.85
Dutch	50%	1,019	1,048	2.5	0.42	5.24	0.46	1,060.51	114.3	1,025.42	103.24	73.68	12.68	70.36	12.74
Dutch	100%	2,047	2,063	3.1	0.69	4.79	0.58	1,056.7	110.86	1,029.16	104.57	73.27	12.76	70.76	12.88
English	30%	1,984	2,037	2.92	0.47	6.91	0.42	969.3	121.48	915.31	103.98	99.04	46.8	94.07	47.12
English	50%	3,241	3,360	3.31	0.63	6.6	0.51	972.14	121.17	923.06	107.32	99.18	45.93	94.65	45.48
English	100%	6,326	6,470	4.03	0.89	6.1	0.66	967.17	119.37	932.77	110.34	99.06	48.39	95.62	45.11
Spanish	30%	1,256	1,296	2.77	0.57	7.22	0.49	975.11	268.88	923.55	267.17	31.94	33.04	32.19	28.15
Spanish	50%	2,066	2,109	3.31	0.82	6.88	0.58	982.72	278.18	935.62	275.11	31.79	28.62	32.25	29.26
Spanish	100%	4,096	4,095	4.15	1.04	6.32	0.73	985.72	277.61	949.51	277.28	32.14	28.07	32.26	28.36

and lexical coverage groups. The bottom row panels visualize average RTs for the positive and negative words across age groups (the 100% lexical coverage only).

Across the three languages, the trajectory of valence change over age was highly comparable, even when considering mildly to extremely valenced words.[3] First, all values of ΔRT were above zero, indicating that responses to negative words were consistently slower than those to positive words (for supporting and conflicting evidence, see Kuperman et al., 2014; Kousta et al., 2011, respectively). Second, the application of the different lexical coverage groups showed that more extremely valenced groups came with a stronger difference between positive and negative words. This is similar to amplification of the age effect on extremely valenced words seen in type and token frequencies in Study 1. Third, values of ΔRT decreased between the ages of 30–39 to 50–59 (in English) or 60+ (in Dutch and Spanish). The change was subtle, ranging from 6 to 7 ms in English, from 9 to 15 ms in Dutch, and from 18 to 23 ms in Spanish (for ΔRT between 30 and 39 and 60+ in each language, depending on the lexical coverage of valence). Importantly, the age-driven decrease in ΔRT was consistent and monotonic. The transition from the age group of 24–29 to 30–39 came with either a strong decrease of 19 ms in ΔRT (Spanish) or effectively no change in either English or Dutch based on the lexical coverage of 100%. This discrepancy may be due partly to differences in the number of observations per word (the lowest in Spanish). Still, over at least three decades (age 30+), the trend indicates that the difference between response latencies to positive and negative words diminished with advancing age.

The mathematical change in ΔRT cannot directly point to the cause of the observed reduction. To address this, Figure 3 (bottom row panels) summarizes mean RTs for positive and negative words in the 100% lexical coverage group across the three languages. It demonstrates that both positive and negative words came with longer RTs when age advanced, but the increase in RTs was greater in positive words. We will return to this effect in Study 2b.

Discussion. In Study 2a, we investigated the influence of age and valence on RTs to English, Dutch, and Spanish words in a visual lexical-decision task. We used ΔRT as a measure of relative change in the affective lexicon between positive and negative words across adulthood. The results indicated a similar cross-linguistic modulation of ΔRT by age. First, ΔRT displayed an overall reduction with advancing age. Second, the change in ΔRT was a result of the RTs to positive words being more affected by age than those to negative words. Specifically, RTs to positive words increased over time at a higher rate than those to negative words. We will pit these findings against existing theoretical accounts in the General Discussion.

The descriptive statistics presented in this section indicated a small effect size, aligning with previous studies on the valence effect in visual word recognition (Kuperman et al., 2014). Additionally, our analyses in Study 2a did not account for many lexical variables that are known to influence lexical decision latencies. The reasons for excluding lexical control variables were as follows. First, not all relevant lexical predictors are publicly available as norms for all the three languages. Second, once the lexical norms available for all languages are matched with the norms for valence, some languages (notably, Spanish) show drastic data sparseness. Study 2b, however, reanalyzes English lexical decision data while taking into account several relevant lexical variables (see, e.g., Baayen, Feldman, & Schreuder, 2006; Balota, Cortese, Sergent-Marshall, Spieler, & Yap, 2004; Yap & Balota, 2009); this is done in order to verify that the observed age-driven changes in recognition of emotional words were not spurious.

Study 2b

This study reanalyzed the RTs to the English positive and negative words with additional controls. First, we conducted a formal statistical test of whether the critical patterns reported in Study 2a for English were reliable: namely, the Age × Valence interaction where both positive and negative words show slower RTs across age groups and the slowdown is especially pronounced in positive words. Importantly, this test—implemented as a regression model—included a large number of other lexical predictors known to influence RTs in lexical decision (see Baayen et al., 2006; Balota et al., 2004; Brysbaert et al., 2011; Keuleers et al., 2010; Yap & Balota, 2009). Thus, we sought to validate the critical interaction over and above the influence of these predictors. A better performance of the model with the critical Age × Valence interaction over a model with main effects of age and valence, while other predictors are controlled for, would be evidence in favor of the interaction.

Second, we explored the possibility that the Age × Valence interaction itself could be further modulated by another lexical property associated with the affective lexicon. A better performance of the model with the critical Age × Valence interaction over a model where age and valence are two of the three terms in a three-way interaction would indicate that the critical interaction is indeed valid across the entire lexical space. A vast majority of lexical properties are likely to change their values across the life span. For instance, the number of orthographic neighbors depends on one's orthographic lexicon size, which changes with age. We also demonstrated changes in word frequency in Study 1. Yet to our knowledge, reliable age-locked estimates are not currently available for these lexical properties. As a result, for this test, we chose word length (in letters) because it is a word property that is not influenced by accumulation of knowledge over time—a five-letter word remains a five-letter word regardless of a person's experience with such words with advancing age—allowing us to keep it constant across the age groups. There are reasons to believe, however, that the well-established effect of word length on RTs may change as a function of age. Age has been shown to be associated with a reduction in perceptual span (Rayner, Castelhano, & Yang, 2009) and visual acuity (Akutsu, Legge, Ross, & Schuebel, 1991). Other changes in oculomotor behavior, such as longer (Rayner et al., 2006) but slower saccadic eye movements (Peltsch, Hemraj, Garcia, & Munoz, 2011) in older readers, also can affect reading performance and subsequently RTs in a visual lexical-decision task, especially in long words. In sum, we tested whether our critical interaction of Age × Valence is reliable on its

[3] The only deviation from this trend was displayed in the Spanish data in which the youngest adults had a substantially longer RTs than the older ones; this is discussed in the Limitations and Future Prospects. However, this deviation does not affect ΔRT, which forms the basis of the analysis in this section.

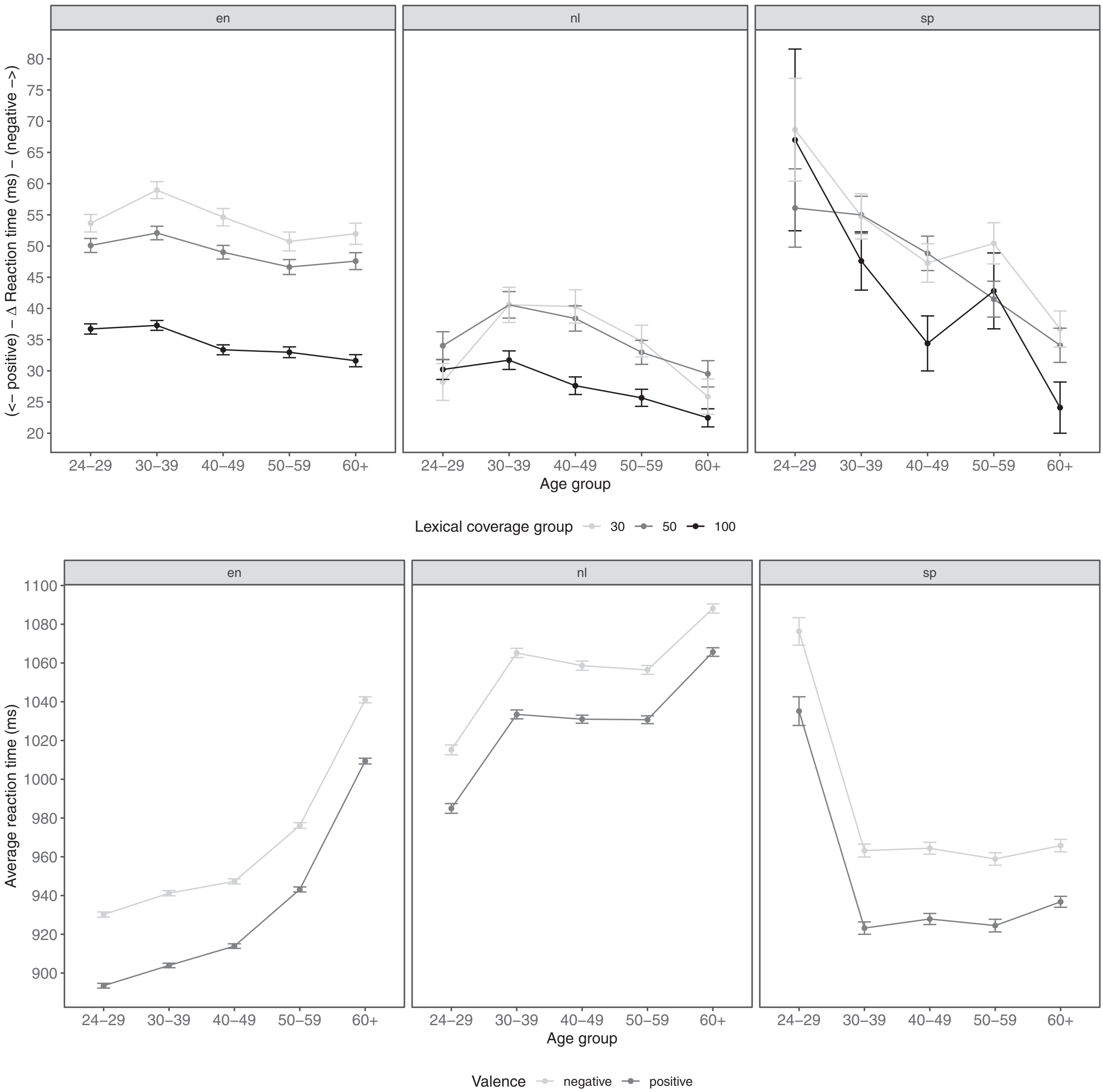

Figure 3. The top panels present the change in the delta RTs of the affective words across adulthood in English (en), Dutch (nl), and Spanish (sp). The error bars correspond to one standard deviation. The bottom panels present the age-related modulation of RTs for the positive and negative words for each of the three languages in the 100% lexical coverage group. The error bars correspond to standard error.

own or whether it is further qualified by a modulating influence of word length.

Method.

Participants, materials, and procedure. The RTs came from the same megastudy on English as in Study 2a. The lexical properties that we considered included affect as a critical independent variable and 10 other lexical predictors. We only considered variables that (a) were publicly available, (b) had a large coverage among the affective words to avoid large-scale data loss, and (c) had been shown previously to influence RTs in a visual lexical-decision task (see Baayen et al., 2006; Balota et al., 2004; Brysbaert et al., 2011; Keuleers et al., 2010; Yap & Balota, 2009). The concreteness norms were obtained from Brysbaert, Warriner, and Kuperman (2014), and the age-of-acquisition norms were obtained from Kuperman, Stadthagen-Gonzalez, and Brysbaert (2012). The remaining variables were extracted from the English Lexicon

Project (Balota et al., 2007). As a frequency norm, we used the subtitle frequency provided in the English Lexicon Project (see Brysbaert & New, 2009 for details). It is important to note that the analysis presented for Study 2b contained only the affective words that had lexical information available in all the publicly available databases; thus, the sample size in Study 2b is somewhat smaller than in 2a. We used the same three pairs of thresholds to specify positive and negative word groups: the median split of the valence distribution, thus covering 100% of available words (the ties were assigned to the lower half); the top and bottom 25% of the valence distribution, thus covering 50% of available words; and the top and bottom 15% (covering 30%). The number of affective words attested in each lexical coverage group was the following: 30%: $n = 3{,}544$; 50%: $n = 5{,}905$; and 100%: $n = 11{,}873$. Finally, the words were divided into positive and negative ones based on the same three lexical coverage groups. The lexical variables and their distribution in each of the lexical coverage groups are presented in Table 5.

Although the positive and negative words displayed differences in terms of lexical properties as reflected by the summary information in Table 5, the valence of a particular word, that is, whether positive or negative, was not highly predictable from the other lexical properties associated with the word. This indicates that valence provides a unique contribution to the semantic structuring of a word. The details of this analysis are provided in online Supplemental Materials S4. The summary information of the RTs (ms) is provided in Table 6, separately for the positive and negative words in each of the lexical coverage groups.

Statistical considerations. To offer evidence for the critical interaction—age and valence—we fitted linear regression models to the data, and the Akaike information criterion (AIC) was used to determine the contribution of a given predictor in the model (Akaike, 1974). Specifically, we used ΔAIC, the difference in AIC between two models. The logic of this method is as follows. We calculated the difference in AIC between a model with a given predictor and a model without that predictor. If the removal of the predictor resulted in an increased AIC value, this less complex model was highly unlikely given the data, thus presenting evidence for the inclusion of the test predictor. As a rule of thumb, a difference in AIC between two models of 2 or less suggests substantial evidence for a particular model, values between 3 and 7 indicate considerably less support, and 10 or greater indicates that the model in question is very unlikely (Burnham & Anderson, 2002). Importantly, this type of model comparison was only carried out for predictors of interest, and other lexical control variables were not removed from the models even if they were not statistically significant to avoid reporting anticonservative results (see Harrell, 2001 for discussion). If the best-fitting model showed that the critical Age × Valence interaction was significant, we considered this as evidence that this critical effect was not spurious and survived even when other major lexical predictors were accounted for.

For the purposes of statistical inference when comparing the RTs of the positive and negative words between the age and the lexical coverage groups, we estimated marginal means for these contrasts (Searle, Speed, & Milliken, 1980) as implemented in the R package emmeans, Version 1.4.1. The estimated marginal means are based on the predictions of the fitted model allowing us to carry out planned comparisons to test the following valence effects: (a) overall slower RTs to the negative than to the positive words, (b) relatively greater slowdown in RTs to the positive than to the negative words with advancing age, and (c) a decrease in the positivity bias effect with advancing age. The estimated p values of the effect were adjusted for multiple comparisons using the Tukey method (Tukey, 1994). Finally, as some of these comparisons are best represented as relative effects, we report these effects as percentages of the estimated marginal means, that is, ratios of the RTs.

Results. We carried out two backward stepwise model-fitting procedures to test for the age-related valence effect on RTs in English, as recommended in Zuur, Ieno, Walker, Saveliev, and Smith (2009). In the first, we tested whether the age-related valence effect was further modulated by length (in letters). The first model specification contained log-transformed RT as the response variable along with the three-way interaction between age, valence, and length. The second model specification contained the same response variable but separate interaction terms, namely age by valence and valence by length. Both of these model specifications included the same set of lexical control variables: log-transformed frequency, orthographic neighborhood, phonolog-

Table 5
Summary Information of the Lexical Variables and Their Distribution in Each of the Lexical Coverage Groups for the Negative and Positive Words

	Lexical coverage: 30%				Lexical coverage: 50%				Lexical coverage: 100%			
	Negative		Positive		Negative		Positive		Negative		Positive	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Frequency (pm)	11.12	48.56	47.88	237.96	9.5	41.8	45.88	274.87	10.28	57.16	36.28	242.64
Length	7.6	2.39	7.35	2.32	7.49	2.39	7.33	2.35	7.31	2.37	7.22	2.35
Orthographic neighborhood	2.76	0.97	2.64	0.92	2.71	0.96	2.65	0.93	2.63	0.95	2.6	0.93
Phonological neighborhood	2.7	1.15	2.6	1.08	2.65	1.13	2.59	1.09	2.59	1.12	2.55	1.09
Bigram frequency (average, log)	8.16	0.45	8.14	0.48	8.14	0.45	8.14	0.47	8.15	0.46	8.15	0.47
Number of phonemes	6.4	2.22	6.11	2.14	6.31	2.21	6.1	2.16	6.16	2.19	6.02	2.15
Number of syllables	2.49	1.06	2.4	1.02	2.44	1.06	2.4	1.03	2.37	1.04	2.34	1.03
Number of morphemes	1.85	0.8	1.71	0.73	1.82	0.8	1.7	0.75	1.77	0.78	1.69	0.75
Age of acquisition	9.67	2.39	7.87	2.53	9.81	2.39	8.15	2.57	9.72	2.47	8.57	2.6
Concreteness	2.95	0.93	3.17	1.14	3.01	0.95	3.28	1.14	3.23	1	3.39	1.1

Table 6
Summary Information of the English Reaction Time (ms) Data for the Negative and Positive Words Broken Down by the Age Groups and the Three Lexical Coverage Groups

	Lexical coverage: 30%				Lexical coverage: 50%				Lexical coverage: 100%			
	Negative		Positive		Negative		Positive		Negative		Positive	
Age group	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
24−29	920.76	105.55	868.54	83.77	925.81	106.19	876.14	88.61	924.52	105.8	888.43	94.24
30−39	935.77	103.68	878.39	80.76	938.44	102.75	887.03	85.8	935.47	103.03	899.04	90.14
40−49	945.31	104.33	892.52	85.5	946.4	102.85	897.92	87.62	942.01	102.62	909.04	92.45
50−59	971.06	112.15	922.92	91.63	973.71	110.77	928.34	95.1	969.05	110.11	937.71	98.79
60+	1,039.05	122.88	989.3	106.52	1,040.63	123.51	994.01	109.82	1,033.61	121.24	1,003.29	113.63

ical neighborhood, log-transformed average bigram frequency, number of phonemes, number of syllables, number of morphemes, age of acquisition, and concreteness. These models were fitted to the three different lexical coverage groups. The results of these fitted models are provided in online Supplemental Materials S3. The model comparison supported the inclusion of separate interaction terms, indicating that the Age × Valence interaction was not modulated by length, and this support was consistent across the three lexical coverage groups.

In the second model-fitting procedure, we tested whether the modulation of the valence effect on RTs by age was supported by the data. We used a third model specification that only differed by the absence of the interaction between age and valence. The model comparison offered evidence for the inclusion of the age-related valence effect and the results given in online Supplemental Materials S3. In sum, the model comparisons across the lexical coverage groups fully supported the hypothesis that age modulated the valence effect on RTs. The summary information of the best-fitting model to English affective words in the three lexical coverage groups is provided in Table 7.

As a global pattern, all affective words elicited an increase in RTs driven by advancing age, that is, a simple main effect of age, and this effect was also consistent across the three lexical coverage groups. This follows the well-attested pattern reported in previous studies (see Ratcliff et al., 2004; Rayner et al., 2006; Salthouse, 1996, among others). It is worth pointing out that the simple main effect of valence was not statistically significant, suggesting that the effect of valence appeared to be strongly modulated by age-related processes. As the main focus of this study is on the age-related valence effect, we will concentrate on the estimated interaction effect of Age × Valence. The estimated effect of this interaction on RTs is visualized in Figure 4. The results present

Table 7
Summary Information of the Best-Fitting Linear Regression Models of English RTs With an Interaction of Valence and Age in the Three Different Lexical Coverage Groups

Variable	Lexical coverage: 30%	Lexical coverage: 50%	Lexical coverage: 100%
Intercept	6.66 (0.01)***	6.66 (0.01)***	6.65 (0.01)***
Frequency (log)	−0.02 (0.00)***	−0.02 (0.00)***	−0.02 (0.00)***
Length (in letters)	0.01 (0.00)***	0.01 (0.00)***	0.01 (0.00)***
Valence: positive	0.01 (0.00)	−0.01 (0.00)	−0.00 (0.00)
Age 30−39	0.02 (0.00)***	0.01 (0.00)***	0.01 (0.00)***
Age 40−49	0.03 (0.00)***	0.02 (0.00)***	0.02 (0.00)***
Age 50−59	0.05 (0.00)***	0.05 (0.00)***	0.05 (0.00)***
Age 60+	0.12 (0.00)***	0.12 (0.00)***	0.11 (0.00)***
Orthographic neighborhood	0.00 (0.00)	0.00 (0.00)*	0.01 (0.00)***
Phonological neighborhood	0.00 (0.00)*	0.00 (0.00)*	0.00 (0.00)*
Bigram frequency (average, log)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)***
Number of phonemes	−0.00 (0.00)	−0.00 (0.00)	−0.00 (0.00)***
Number of syllables	0.02 (0.00)***	0.02 (0.00)***	0.02 (0.00)***
Number of morphemes	−0.01 (0.00)***	−0.01 (0.00)***	−0.01 (0.00)***
Age of acquisition	0.01 (0.00)***	0.01 (0.00)***	0.01 (0.00)***
Concreteness	0.00 (0.00)***	0.00 (0.00)***	0.00 (0.00)
Length (in letters), valence: positive	−0.01 (0.00)***	−0.00 (0.00)***	−0.00 (0.00)***
Valence: positive, age 30−39	−0.00 (0.00)	−0.00 (0.00)	0.00 (0.00)
Valence: positive, age 40−49	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Valence: positive, age 50−59	0.01 (0.00)	0.01 (0.00)*	0.01 (0.00)**
Valence: positive, age 60+	0.01 (0.00)*	0.01 (0.00)**	0.01 (0.00)***
R^2	0.47	0.45	0.42
Adjusted R^2	0.47	0.45	0.42
Root mean square error	0.08	0.08	0.09

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

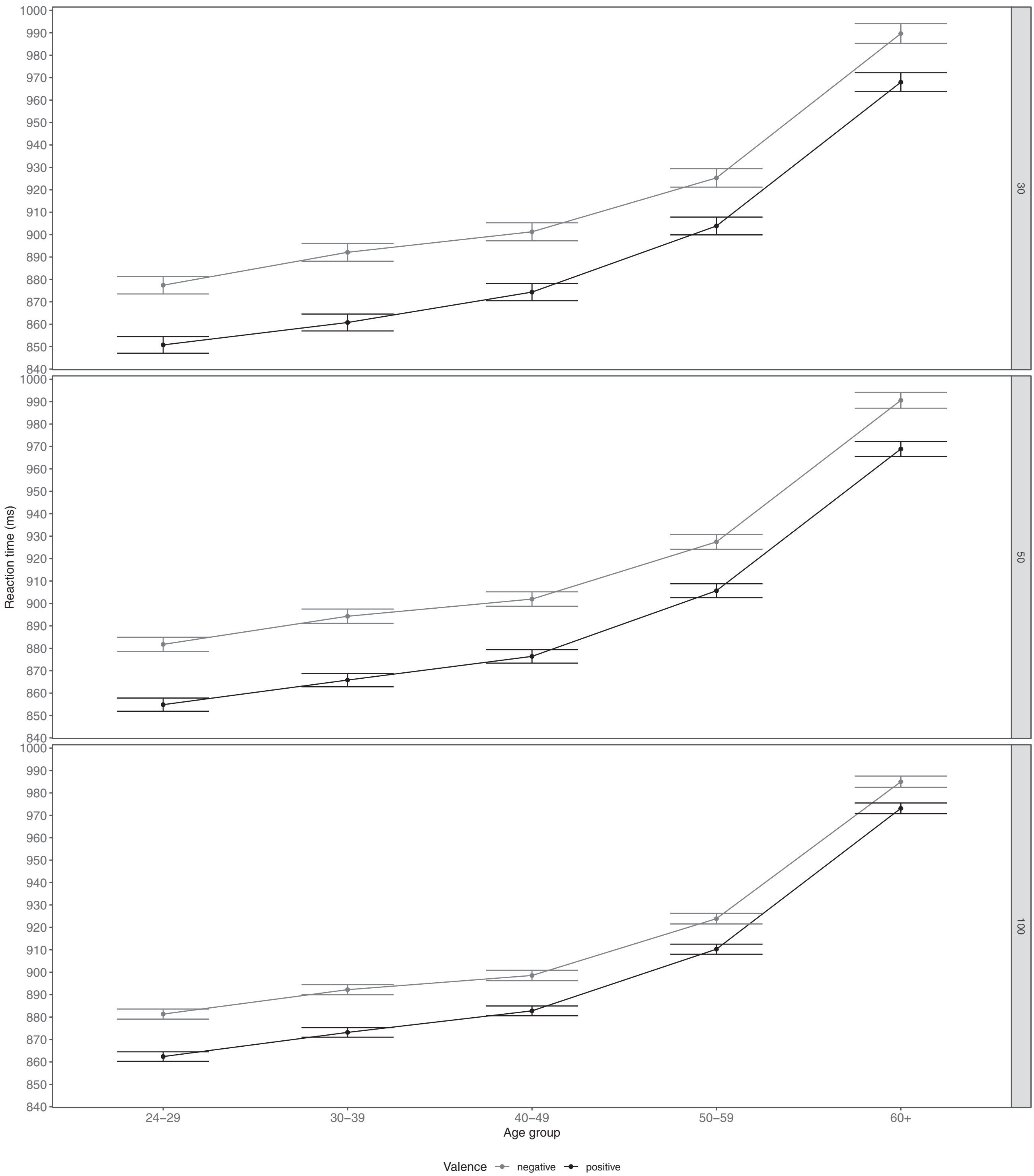

Figure 4. The estimated partial effect of the age and valence interaction on RTs across the three different lexical coverage groups in English. The RTs were back-transformed from log scale to milliseconds.

three age-related modulations of the valence effect that are relevant for the purposes of the present study and are discussed separately below.

The first age-related valence effect discussed here is concerned with the effect itself across adulthood; namely, it displayed differential patterns for the negative and positive words. The negative words were consistently processed slower than the positive ones, and this valence effect was fairly consistent across the three different lexical coverage groups (see Figure 4). For example, the estimated average RT (ms) was 881.34 (95% CI [879.09, 883.59]) for the negative words and 862.39 ([860.27, 864.51]) for the positive ones among the youngest adult group in the 100% lexical coverage group, corresponding to a facilitatory effect of 2.2%. In the case of the oldest adult group, the estimated average RT for the negative words was 984.98 ([982.46, 987.5]) and 973.12 ([970.73, 975.51]) for the positive ones, respectively. This corresponded to a facilitatory effect of 1.22%.

The second effect was concerned with the modulation of RTs by the age-related valence effect. The results indicated that the increase in RTs was greater with the positive words, and this effect was especially noticeable in the 100% lexical coverage group among the youngest and the oldest adults. For example, in the case of the negative words, the ratio of the RTs between the youngest and the oldest adult group was estimated to be 0.89 ($SE = 0.001$), corresponding to a reduction of 11% in the oldest adult group. For the positive words, the ratio was estimated to be 0.8862 ($SE = 0.14$), translating into a 11.38% reduction in the oldest adult group. The difference in these age-related valence effects was also statistically significant for the negative words, $t(59{,}344) = -69.33$, $p < .001$, and for the positive words, $t(59{,}344) = -76.91$, $p < .001$. Thus, the results offered support for the modulation of the age-related valence effect where the increase in RTs was greater for the positive words with advancing age.

The third age-related valence effect concerned the relative modulation of the age-related valence effects themselves. It is related to positivity bias and its modulation by age; namely, the facilitatory effect of positivity bias was reduced as age advanced. This relative modulation of the valence effect is clearly visible in Figure 4 when we contrast the youngest and the oldest adult groups, and it was strongest in the 100% lexical coverage group. For example, the observed facilitatory effect of the positivity bias was estimated to be 1.22% in the oldest adult group and 2.2% in the youngest. The reduction in the facilitatory effect of the positivity bias, albeit small, was estimated to be 0.97% and was statistically significant, $t(59{,}344) = 4.29$, $p < .001$. This reduction in positivity bias between the youngest and the oldest adult group was also statistically significant in the 50% lexical coverage group with an estimated reduction of 0.89%, $t(29{,}504) = 2.82$, $p < .001$. Finally, in the 30% lexical coverage group, the reduction was estimated to be 0.87% and was also statistically significant, $t(17{,}699) = 2.17$, $p = .03$.

Discussion. In Study 2b, we investigated the role of age-related valence effects on RTs to English words in a visual lexical-decision task while controlling for other lexical properties associated with the affective words. The results of the analysis provided converging evidence for the cross-linguistic age-related valence effects reported in Study 2a. We carried out model comparisons that confirmed the support for the age-related valence effect in RTs. Additionally, the model comparisons also offered evidence that the critical interaction between age and valence was unlikely to be further modulated by length (in letters) given the data. We used length as it can serve as an excellent control variable in aging studies for two reasons. First, it is not influenced by accumulation of knowledge across the life span compared to frequency of use, for example. Second, its influence in language comprehension is connected to vision, and aging is known be associated with physiological changes in vision that can affect reading performance such as reduction in perceptual span.

The best-fitting model also provided evidence for the following age-related valence effects on RTs in English. First, the positive words were consistently processed faster than the negative ones, regardless of how extreme the valence response was. Second, the positive words were more affected by age-related reduction in RTs than the negative words. Thus, the positive words were estimated to display a greater increase in RTs with advancing age. Third, the facilitatory effect of the positivity bias reduced with advancing age.

General Discussion

This article examined production and comprehension of affective language across adulthood (from 24 years of age). The overall goal was to identify whether and how strongly age modulates the distribution of affective information in naturally occurring language production and how these distributional shifts influence comprehension behavior. To this end, we recruited massive data sets of written productions (Facebook status updates from over 20,000 users) and collections of lexical decision data in English, Dutch, and Spanish (responses from thousands of users to over 40,000 words in each corpus). In each data set and task, we focused on the critical interaction of age by valence: Namely, we were interested in whether language production or comprehension behavior differed as a function of valence and whether these affective differences varied across age.

Our central finding was uniform across tasks, languages, and cohorts. In both natural written productions and word recognition data, we observed an Age × Valence interaction. We viewed the behavioral data as a (partial) reflection of cognitive, emotional, and other changes that age progression engenders in a human adult. Additionally, we provided evidence that the valence of a particular word is not strongly predictable from the other lexical properties associated with the word, as discussed in online Supplemental Materials S4. This further supports the role of valence as an important cue associated with semantic structuring in language. Thus, below, we discuss the direction and the functional form of these interactions in light of the theoretical accounts of affective lexicon as outlined in the introduction.

Data from the free-form social media texts in English enabled quantification of the structure of the affective lexicon in over 20,000 users from 24 to 85 years of age (Study 1). A central observation was that older individuals used a larger number of distinct positive words (i.e., an increase in positive word types) and that they also used an average positive word more often (i.e., an increase in positive word tokens). The amplification of the positive bias was gradual rather than confined to a specific age group. This finding was robustly replicated across multiple methods of data aggregation. It converges with previous reports of a trend in older adults to experience or express fewer negative emotions in a variety of tasks related to memory and emotion recognition (see Carstensen & DeLiema, 2018; Reed et al., 2014 for an overview). As in prior studies (e.g., Carstensen & Turk-Charles, 1994; Kalenzaga et al., 2016; Reed & Carstensen, 2012), we link the gradually increasing positivity bias in older adults with their improving mastery of emotion regulation strategies, which highlight positive experiences over negative ones.

The novel contribution of these production data is threefold. First, it uncovers evidence that runs counter to theoretical accounts positing a null effect of age on emotion regulation and on tasks involving expression or recognition of affect (Comblain et al., 2004; Denburg et al., 2003; Eich & Castel, 2016; Leshikar et al., 2015). Second, it harnesses a very large high-power data set of ecologically valid, free-form data representing a broad range of age, ability, personality, and other properties relevant for individual variability in cognition and emotion. Thus, the present findings serve as an important replication and validation of the results often obtained from relatively small cohorts of participants, drastically different in age and exposed to a relatively small number of tightly controlled experimental stimuli. Third, our findings in language production are useful for both predicting and constraining the range of theoretical possibilities regarding the roles of aging and affect in word recognition behavior; for an elaboration of a hypothesis linking production and comprehension, see below.

Analyses of word recognition data across four decades of adulthood (24 years old and older) and three languages uncovered one and the same pattern (Study 2a). Finding (a) was that all words elicited longer lexical decision RTs in older participants compared to younger ones. This is fully in line with reports of an age-driven slowdown in the speed of lexical processing. As such, it is compatible with predictions of two radically opposing accounts. In the "cognitive decline" account, the slowdown is due to a deficient or suboptimal cognitive functioning caused by aging (e.g., Salthouse, 2009), while in the "lifelong learning" account, the slowdown is not a deficit but an expected result of the continuously growing vocabulary and a greater effort of discriminating one word from an increasing number of competitors (see Ramscar et al., 2014). Finding (a) alone does not provide direct evidence in favor of either account.

Finding (b) was that the difference in RTs to very positive and very negative words declined with age. Finding (c) was that this was due to responses to positive words slowing down more strongly with age than responses to negative words. To rephrase, the overall reduction in response latencies observed across the board as readers' age was more pronounced in positive rather than negative words. Study 2b further confirmed the validity of all findings in the English data set, over and above the impact of other lexical predictors.

Findings (b) and (c) are theoretically important. Natural written production data revealed that as they age, people use an ever-larger number of positive word types and use an average positive word more often than negative ones (more positive word tokens). As argued in the introduction, an increase in positive word tokens is predicted to facilitate recognition of positive words; under this frequency-based or "use it or lose it" account, the ease of word recognition is directly proportional to one's familiarity with the word, gauged as the amount of exposure to the word or its frequency of occurrence (Baayen, 2010; Brysbaert et al., 2018). Yet an increase in positive word types predicts the opposite under the "lifelong learning" account. Namely, it predicts that psychological positivity becomes a less salient cue to discriminating a word from other words in the mental lexicon (Alves et al., 2017; Garcia et al., 2012). The crowding of the lexical space associated with positive connotations in older individuals is expected to lead to a relative slowdown in positive words over age. Finding (c) offers a ready confirmation for the "lifelong learning" account; with age, RTs to positive words grow slower than RTs to negative words. Critically, finding (c) runs counter to the predictions of the frequency-based account. It also cannot be explained under the cognitive decline account, which posits a general slowdown of all verbal processes (see Laver & Burke, 1993 for discussion). Second, to our knowledge, the deficits that aging is proposed to bring to attention, memory, and other cognitive processes are not argued to be sensitive to any aspect of lexical semantics, including affective lexical connotations (see Burke & MacKay, 1997; Thornton & Light, 2006, among others). Importantly, the Age $\times$ Valence interaction indicates that it is not just accumulation of semantic information over time that can facilitate processing, as discussed in Laver and Burke (1993), for example, but the context of the accumulation itself must be taken into account in order to begin to model the differential valence effect reported in this study. The crowding of the lexical space, and specifically the affective lexicon, also can be used to motivate the shrinkage of the difference in RTs to the positive and negative words as the informativity of a cue is not only determined by the stimulus itself but also the relation of the cue to other stimuli (for discussion, see Ramscar, Dye, & McCauley, 2013; Rescorla, 2001). Thus, the shrinkage of the positivity bias suggests that as the use of the affective lexicon as a whole increases with advancing age, the valence loses its informativity as a cue, resulting in a shrinkage of the positivity bias effect in comprehension.

Given the context of how language can accumulate over time, the results presented here cannot rule out the possibility of aging influencing affective lexical processing in multiple ways simultaneously. Aging comes with an increase in positivity bias, both in word types and tokens. It is likely then that the counterdirected trends—a processing advantage coming with a higher token frequency and a discrimination penalty from a higher type frequency—are present in the structure of one's vocabulary as it develops across the life span. If so, the chronometric data on word recognition reflect a juxtaposition of effects on lexical processing, some of which mitigate each other.

What we do establish in this study is that central findings cannot be explained without involving one of the conflicting accounts, that is, the lifelong learning account. Over and above possible other influences, "lifelong learning" is a mechanism that can explain both the general effect of aging on language processing found here and in much previous research (Baayen et al., 2017; Milin et al., 2017; Ramscar, Hendrix, et al., 2013) and the newly reported Age $\times$ Valence interaction in language comprehension. This account satisfies the principle of parsimony (see Baltes, 1987; Salthouse, 2009; Singer, Verhaeghen, Ghisletta, Lindenberger, & Baltes, 2003, among others) as the account can be used to motivate the patterns reported for production and comprehension. In this study, we have not presented a computational model of lifelong learning but pointed to general principles that a cognitively plausible model should be able to account for. We leave it to future studies to implement a precise model, e.g., in the framework of discriminative learning (Baayen et al., 2017; Milin et al., 2017; Ramscar, Hendrix, et al., 2013; Ramscar et al., 2014). At the same time, it is noteworthy that while word semantics is in the focus of any account of language learning, to our knowledge, connotations are rarely discussed in the literature on discriminative learning. This article provides evidence that emotional connotations, like positivity or negativity, can serve as cues toward associating forms and meanings and that—like with other cues—their informativity can change as a result of age-related changes in the distributional patterns of the mental lexicon as a whole (see Hinojosa, Moreno, & Ferré, 2019 for similar observation).

The results reported above go beyond a novel large-scale empirical contribution to understanding age effects in production and comprehension of affective language. As stated in the introduction, we agree with the view that production and comprehension behaviors are shaped by the same set of (often conflicting) cognitive, physiological, and communicative processes (MacDonald, 2013; Pickering & Garrod, 2013); one of these processes is aging. While proposals on the actual mechanism providing the production-comprehension link differ (see the discussion in the special issue by MacDonald, 2013), they converge on the notion that comprehenders are sensitive to statistical probabilities of linguistic units that emerge in production. Furthermore, these probabilities guide comprehenders in forming expectations about the upcoming material and allocating their attentional resources to these expectations proportionally to how probable they are to occur (Kuperberg & Jaeger, 2016; Levy, 2008; Ramscar et al., 2014). Thus, distributional biases in language that are shaped by, and revealed in, production also shape the comprehension behavior. These distributional biases are not static, either in a language community or in an individual; they change both at the macrolevel—due to constant changes in the extralinguistic environment, in language, and in an individual organism—and the microlevel—due to continuous exposure to the new linguistic input.

For the purposes of this article, an important implication of the coordinated nature of production and comprehension behaviors is that we can interpret the Age × Valence interaction observed as both a constraining and explanatory factor of the Age × Valence interaction that we report in word recognition studies. This is what underlies our ability to use production and comprehension data jointly as a testbed for a number of existing and logically possible theoretical accounts outlined in the introduction. However, it is worth pointing out that we have presented evidence for the modulation of the valence effect with advancing age in this study. We have not presented evidence for a change in valence itself across adulthood, that is, for a valence trajectory associated with a given word. For example, it is plausible that the perceived valence of a word also changes as a function of age, but it is unlikely that this type of valence trajectory, even if present, would substantially alter the results presented here as previous studies have reported only small differences in valence ratings—for example, between younger and older Finnish adults (Söderholm, Häyry, Laine, & Karrasch, 2013) and among German children and adults (Bahn, Kauschke, Vesker, & Schwarzer, 2018; but see Monnier & Syssau, 2017 for French).

We present novel evidence on the role of affect on language production and word recognition over four decades of adult age and in three languages representing multiple national communities. This evidence tests the validity of existing theoretical proposals of the interaction between language, emotion, and age. It does so by identifying distributional patterns of affective language in natural written productions and pitting them against word recognition behavior, using large data sets for both tasks. Under the hypothesis linking production and comprehension via statistics of language, we were able to critically evaluate a spectrum of competing accounts. The results of this study are most readily compatible with the "lifelong learning" account (Baayen et al., 2017; Milin et al., 2017; Ramscar et al., 2014; Rescorla, 1988; Rescorla & Wagner, 1972; for a broader discussion, see Siegel & Allan, 1996). This account presents aging as a continuous accumulation of lexical, semantic, and—by extension—affective knowledge. It construes behavioral differences in processing positive and negative words as a direct consequence of growing information-processing demands on word recognition in an expanding lexicon. Our findings demonstrate that the cognitive demands of word recognition and discrimination are codetermined by the structure of the affective lexicon. While the effect size of this modulation was estimated to be small, it is in line with previous studies and resulting from a task that did not require an overt emotional response. Even small effects can be integral parts of a detailed understanding of cognition (Salthouse, 2012). Further work is required to expand this effort over additional semantic variables and generate a comprehensive account of word processing over the life span.

Limitations and Future Prospects

Our use of Facebook data as a source of textual and affective information requires a discussion of how generalizable the present findings are to the general population. We discuss two potentially relevant aspects of the Facebook data: (a) demographics of Facebook users versus population at large and (b) affective and stylistic demands of writing on Facebook.

Online data sources tend to provide access to both a larger and more diverse pool of participants compared to traditional convenience pools. However, these welcome characteristics do not automatically mean that the sampled data can be taken to represent the target population as a whole (Goodman, Cryder, & Cheema, 2013; Paolacci & Chandler, 2014). Self-selection bias of individuals choosing to use a certain social media platform (or participate in any online experimental study) is an important factor to consider. Our choice of Facebook is partly determined by the breadth of its user base: 79% of Americans used Facebook in 2019, and it is also widely used globally as compared to, say, Twitter, which is used by 22% of U.S. adults (https://www.pewresearch.org/Internet/fact-sheet/social-media/) and is primarily concentrated in the United States, Japan, and Russia (https://www.statista.com/statistics/242606/number-of-active-twitter-users-in-selected-countries/). Facebook is also widely used across all age groups: 62% of online users aged 65+ are on Facebook, as are 72% of online users between the ages of 50 and 64 (https://www.omnicoreagency.com/facebook-statistics/). Still, several caveats are in order.

While fairly representative of the online community, on average, U.S.-based Facebook users are younger, are better educated, and have higher incomes than the U.S. population in general. In our data, the median age of our Facebook cohort of 22,000 users is 31 years old, while the median age in the United States in the year of data collection was 36.7 (https://www.census.gov/data/tables/2012/demo/age-and-sex/2012-age-sex-composition.html). Reasons that are most often cited as influential for the differences in age distribution between online users and the population at large are different levels of digital literacy and access to required technology (Correa, Hinsley, & De Zuniga, 2010; Jung, Walden, Johnson, & Sundar, 2017). We have no access to information about the socioeconomic status, educational, or technical proficiency levels of contributors to the present Facebook text base. Thus, it is logically possible that self-selection across age groups of Facebook users leads to an observed consistent increase in the positivity bias time-locked with age. While this explanation cannot be ruled out based on the current data, we find it unlikely. This is because the increase in positivity bias is observed across the entire age range and also in the age groups that are very well represented in the Facebook cohort. Also, our observation of the age-related increase in the positivity bias in naturally written texts dovetails perfectly with similar observations obtained from experimental paradigms unaffected by the self-selection bias (see above).

In our opinion, an acceptable solution for testing the validity of age-related findings made on observational data from social media is to replicate the analyses in, say, 10 years. At that time, all age groups will be represented by an even broader user base than today, as well as by individuals who are more technologically savvy and accustomed to the use of social media than the present cohorts in the same age groups; the difference is expected to be most drastic in the older age groups (65+) that will be occupied by the those presently 55+ years old (see Charness & Boot, 2009). If similar patterns of affective language use are replicated, they are not due to the self-selection bias. It is worth pointing out that sampling biases are not limited to the Facebook data used but also extend to any online study such as the data originating from the megastudies analyzed in this study. For example, this might be the case with the Spanish data set as the youngest adults displayed a different pattern compared to ones present in the Dutch and the English data. While this did not affect the results presented in this study, as they were based on ΔRTs, this line of investigation should receive closer examination in future studies to better understand potential differences stemming from sampling biases and demographic information.

Another potential confound in the patterns of affective language use on Facebook may stem from the linguistic register accepted in this social platform. Register, or a text variety associated with a specific situational context, is one of the strongest predictors of linguistic variation; online texts are known to vary substantially in their composition and language use (Biber & Egbert, 2018). For instance, Jaidka, Guntuku, Buffone, Schwartz, and Ungar (2018) demonstrated that the same individuals were more likely to use Facebook to convey personal concerns and emotions, while their Twitter usage was associated with personal needs and drives (Jaidka et al., 2018). It is thus possible that our choice of Facebook as a data source has made salient some specific aspects of individual world outlook and affective perception and downplayed others due to stylistic and linguistic register demands of this social media platform. However, we are not aware of any evidence that status updates in Facebook especially amplify positive rather than negative dimensions of affective language. Furthermore, there is no a priori reason to expect that the register-driven features of Facebook would influence different age groups in a systematic and gradient way, with older age groups using more positive words. A definitive answer to the role of register in age-related patterns of language use will require further linguistic research, which will evaluate affective language in other large and diverse sources of texts produced naturally by individuals of different ages.

Context

This study emerged as part of an ongoing research project by Aki-Juhani Kyröläinen and Victor Kuperman on age-related changes of distributional biases in language and how they affect language production and comprehension. This research naturally connects to the prior work by Emmanuel Keuleers, Paweł Mandera, and Marc Brysbaert on aging and visual word recognition and, importantly, to their behavioral studies conducted on a massive scale. These studies have made it possible to test the theoretical predictions stemming from a number of different accounts discussed in this study. Finally, the line of research fostered through this collaboration is currently being expanded to other aspects of visual word processing across languages in adulthood.

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