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Underdeveloped recollection during adolescence: Semantic elaboration and inhibition as underlying mechanisms

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ABSTRACT

Recognition memory abilities undergo important developmental changes until adulthood, with earlier studies showing different trajectories for recollection and familiarity-based processes. However, previous work has primarily focused on childhood, and differences in memory retrieval, notably in recollection, between adolescents and adults, have been hard to confirm. To address this gap in the literature and to better characterize the development of recollection and familiarity during adolescence, we applied the process dissociation procedure to a word recognition memory task, after semantic and perceptual encoding of words, in adolescents (n = 30, 13–15 years of age) and young adults (n = 30, 20–22 years). Relative to young adults, adolescents' lower recognition memory performance was restricted to context recollection of semantically encoded items. This effect was predicted by individual differences in inhibitory control abilities. These findings highlight the distinct developmental trajectories of familiarity and context recollection over the course of adolescence, and suggest that semantic elaboration and inhibition are two key mechanisms toward the full maturation of recollection processes.

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Introduction

Episodic memory is the ability through which we form and retrieve information about past events and their associated contextual details (Tulving, 1985). Studies with adults have postulated that the retrieval of past episodes relies on two distinct and independent processes: recollection and familiarity (Jacoby, 1991; Mandler, 1980; Yonelinas, 2002; Yonelinas, Otten, Shaw, & Rugg, 2005). Recollection refers to the ability to vividly and consciously retrieve an event along with its contextual details (e.g., "I remember I met Alex at a party"), whereas familiarity denotes the feeling that an event has happened before without the conscious retrieval of specific details (e.g., "I know Alex from somewhere, but I don't know if I met her at a party or in a bar"). Most studies assume that recollection is a single process, but a recent approach has proposed that recollection includes two distinct components: context and target recollection (Brainerd, Gomes, & Moran, 2014; Brainerd, Gomes, & Nakamura, 2015). Context recollection refers to the conscious reinstatement of contextual details that accompanied the item's presentation. This form of recollection prevails in recognition research, where participants are often required to remember specific contextual details of the previous encounter with the item (e.g., the task performed or the color in which the item was presented). Target recollection reflects the conscious retrieval of the items per se, allowing discriminating between a target item whose presentation is clearly remembered and a related lure. Target recollection has gained prominence in the false memory literature because it underlies the ability to correctly reject related distractors (Brainerd et al., 2014).

There is solid evidence for a dissociation between recollection and familiarity throughout development, although the developmental trajectories of these processes depend on the type of retrieval involved, that is, recall or recognition. Brainerd, Reyna, and Howe (2009) analyzed a large corpus of data from recall studies (including associative, cued, and free recall) with children (7–8 years of age), adolescents (11–12 years), young adults (20–21 years), and older adults (70–71 years). They found that improvements in recall from adolescence to adulthood were almost entirely due to familiarity, not recollection. Conversely, in recognition studies, there is large agreement that familiarity stabilizes during early childhood whereas recollection, notably context recollection, improves throughout adolescence (Anooshian, 1999; Billingsley, Smith, & McAndrews, 2002; Brainerd, Holliday, & Reyna, 2004; Ghetti & Angelini, 2008; Ghetti & Lee, 2014; Ofen et al., 2007). However, this developmental research has primarily focused on childhood. In the few recognition memory studies directly comparing adolescents and adults, behavioral differences in recollection between these two age groups have been hard to find (e.g., Friedman, de Chastelaine, Nessler, & Malcolm, 2010; Ghetti & Angelini, 2008). To address this gap in the literature, we probed context recollection and familiarity processes in an objective manner in adolescents and young adults to elucidate potential differences in the developmental trajectories of those processes. We focused on context recollection and familiarity because these are the retrieval processes most frequently studied in the adult and child literatures and are commonly distinguished in recognition memory studies. Furthermore, we explored the specific mechanisms that underlie context recollection of past events in both age groups, providing insight into the nature of the presumed differences in memory performance.

Recognition memory studies with adolescents

Ghetti and Angelini (2008) examined recognition memory for drawings in children (6, 8, and 10 years of age), adolescents (14 years), and young adults (18 years) using the receiver operating characteristic (ROC) procedure (Yonelinas, 1994) to measure recollection[1] and familiarity processes. They found that familiarity increased during childhood (stabilizing after 8 years of age) and that recollection continued to increase from childhood to adolescence. However, they did not find differences between adolescents and young adults. In a functional magnetic resonance imaging (fMRI) study using the remember–know paradigm on previously encoded scenes in 8- to 24-year-old participants, Ofen et al.

[1] Several studies refer to recollection as a univariate process without distinguishing between context and target recollection. In these cases, we use the term recollection without further characterization of the type of recollection involved.

(2007) found an interaction between memory processes and age groups; unlike familiarity, recollection improved significantly with age. At a neural level, activation in the prefrontal cortex (PFC) during successful memory formation increased with age and correlated with subsequent memory for specific details of the scenes. The results suggest that age-dependent maturation of the PFC is critical for the formation of detailed memories. Yet, the correlational design of this study precludes a more definitive conclusion regarding potential differences between adolescents and adults. Friedman et al. (2010) collected behavioral and event-related potential (ERP) data with children (9–10 years of age), adolescents (13–14 years), younger adults (20–30 years), and older adults (65–85 years) in a recognition memory task for unfamiliar symbols. Using the remember–know paradigm, the authors found a tendency for an increase in recollection from adolescents to young adults, but this difference was not statistically significant. Moreover, the parietal episodic memory effect, an ERP correlate of recollection, was found for children, adolescents, and young adults. Reduced recollective processing was confined to older adults. Surprisingly, the authors also found a decrease in familiarity from adolescence to adulthood, which denotes some inconsistency in the recognition memory literature regarding the development of familiarity (see also Koenig, Wimmer, & Hollins, 2015; Odegard, Holliday, Brainerd, & Reyna, 2008). In another ERP study, Sprondel, Kipp, and Mecklinger (2012) tested adolescents (13–14 years of age) and adults (19–29 years) in a memory exclusion task that tackles context recollection processes. The ability to discriminate target words from nontargets and new words improved with age, suggesting that memory abilities differ in adolescents and adults when recollection processes are required. ERP correlates of recollection also differed between adolescents and adults, supporting the protracted maturation of these processes. However, by using an exclusion task only, the study could not directly disentangle context recollection and familiarity processes and therefore it did not examine whether their developmental patterns are similar or distinct. Thus, it is generally agreed that further work with adolescents is needed (Ghetti & Bunge, 2012), not only to fill in the gap between childhood and adulthood but also to clarify the various findings with adolescents.

Recollection and familiarity estimates

A key aspect for understanding the diversity of results in recognition memory studies with adolescents concerns the methods used to estimate recollection and familiarity (Ghetti & Lee, 2014; Yonelinas, 2002). Most studies have used the remember–know paradigm (e.g., Billingsley et al., 2002; Henson, Rugg, Shallice, Josephs, & Dolan, 1999; Ofen et al., 2007; Rhodes, Murphy, & Hancock, 2011), whereas others have employed the ROC procedure (e.g., Ghetti & Angelini, 2008; Yonelinas, 1994). Although these approaches have been extensively used with adults (Yonelinas, 2002), their use with children and adolescents should be viewed with caution. In the remember–know paradigm, for items judged as "old", participants need to indicate whether they "remember" seeing those items (an index of recollection) or whether they "know" that the items appeared before (a familiarity estimate). Thus, this paradigm requires direct introspection into memory states. As for the ROC procedure, even though it does not involve such a subjective state of awareness, it relies on reported confidence ratings. An ROC curve is a function that relates hit rates to false alarm rates across different response criteria measured in terms of response confidence (Macmillan & Creelman, 2004). Previous studies have postulated that metamemory abilities are still under development during childhood (Ghetti, Mirandola, Angelini, Cornoldi, & Ciaramelli, 2011; Roebers, 2002) and even into adolescence (Fandakova et al., 2017). This raises the question as to whether the observed differences in recollection and familiarity in adolescents indeed demonstrate different episodic memory processes or instead reflect the subjective ability to report on memory performance (Koenig et al., 2015).

The conjoint recognition procedure (e.g., Odegard et al., 2008) overcomes the need for self-report of memory performance and allows disentangling among target recollection, context recollection, and familiarity. In this paradigm, participants are tested in their recognition abilities under three different conditions: recognize previously presented (i.e., old) items, identify distractors that are semantically related to old items, and detect both old items and semantically related distractors. Despite the advantage of allowing an objective estimate of three retrieval processes, this paradigm can only be implemented with semantically organized stimuli (Ghetti & Lee, 2014).

Another well-established paradigm is the process dissociation procedure (PDP; Jacoby, 1991; Yonelinas & Jacoby, 2012), which allows dissociating and estimating the contribution of context recollection and familiarity processes based on objective memory retrieval responses, rather than on subjective answers, as well as obtaining estimates for both semantic and nonsemantic material. Furthermore, the PDP measures context recollection and familiarity in the same metrics (i.e., in the same scale from 0 to 1) as opposed to the ROC procedure, which allows for a direct comparison between the two processes estimates.

In the classical PDP (Jacoby, Toth, & Yonelinas, 1993), participants study two lists of words (List 1 and List 2) and subsequently perform two retrieval tasks. In the inclusion condition (*i*), participants must recognize all old words (from Lists 1 and 2) and reject new words (i.e., is this word old?). In the exclusion condition (*e*), participants are asked to recognize words from only one of the lists and to exclude both words from the other list and new words (i.e., is this word from List 1?). Whereas in the inclusion condition both context recollection (R) and familiarity (F) converge for the requested answer [(i) hits $= R + F - (R \cap F)$, discounting the possibility of both processes co-occurring], in the exclusion condition the two processes act in opposition and come into conflict for the correct answer's achievement (Yonelinas & Jacoby, 2012). In the exclusion condition, context recollection often promotes the correct response because participants are able to monitor the word's context. Conversely, familiarity-based processes may lead to incorrect answers because they do not allow discriminating the word's context (List 1 or 2). Thus, false alarms in the exclusion condition are taken as a consequence of familiarity processes [(e) false alarms $= F \times (1 - R)$, accounting for familiarity and discounting the possibility of context recollection processes]. After collecting hits and false alarms from the inclusion and exclusion conditions [(i) and (e) equations, respectively], it is possible to disentangle and estimate the proportion of context recollection and familiarity processes for each participant:

$$R = \text{hits} - \text{false alarms}; \; F = \text{false alarms}/(1 - R)$$

Over the past three decades, research on the dual processing of memory using the PDP has proliferated and allowed validating this paradigm under two core assumptions (for reviews, see Yonelinas, 2002; Yonelinas & Jacoby, 2012). First, in agreement with most dual-process models, the PDP assumes that context recollection and familiarity are independent memory processes (thus, $R \cap F = R \times F$), an assumption that has been supported by various behavioral studies (e.g., Ghetti & Angelini, 2008; Koenig et al., 2015; Yonelinas, 2002; Yonelinas & Jacoby, 2012) and neuroimaging studies (e.g., Ghetti & Bunge, 2012; Henson et al., 1999; Ofen et al., 2007; Yonelinas et al., 2005). Second, it assumes that context recollection and familiarity have the same predominance in both the inclusion and exclusion conditions. To check this assumption, analyzing the false alarm rate for new words is recommended. If this is equivalent in the inclusion and exclusion conditions, then one can presume that participants' reliance on context recollection and familiarity is similar in both conditions (Jacoby et al., 1993).

To date, several developmental studies have used recognition memory tasks similar to the exclusion condition (e.g., Czernochowski, Mecklinger, Johansson, & Brinkmann, 2005; de Chastelaine, Friedman, & Cycowicz, 2007; Sprondel et al., 2012). Yet, few have implemented the full PDP with subsequent parameter estimates. Anooshian (1999), who studied recognition memory of video frames in children (4–5 years of age) and adults (18–37 years), found similar levels of familiarity between the two age groups but higher levels of context recollection during adulthood—the most consensual developmental pattern (e.g., Ghetti & Angelini, 2008; Ofen et al., 2007). In contrast, Koenig et al. (2015), using the PDP in drawings recognition, reported that familiarity increased from 5 years of age to adulthood, whereas the levels of context recollection did not differ from 7 years of age onward. Yet again, these studies did not inspect changes during adolescence; they focused on childhood and adulthood, inferring the adolescent developmental processes.

Underlying cognitive control mechanisms

In the PDP literature, recollection and familiarity have been closely associated with controlled and automatic processes, respectively. According to the dual-process models of recognition memory, familiarity is faster and more automatic, whereas context recollection has been regarded as a more effortful process associated with greater control and strategic processes that guide retrieval (Sprondel et al., 2012; Yonelinas & Jacoby, 2012). In line with this view, several studies have shown that cognitive control is often engaged in the service of memory, namely to support the strategic recollection of contextual details and the inhibition of confounding information (Dobbins, Foley, Schacter, & Wagner, 2002; Levy & Anderson, 2002). Yet, whether recollection and familiarity depend on controlled and automatic processes, respectively, is still a matter of debate. Using the conjoint recognition paradigm, Brainerd, Nakamura, and Lee (2019) found that for correctly recognized old items, the speed of recollection did not differ from the speed of familiarity-based decisions. Moreover, in memory recall research, familiarity has been revealed to be slower than context recollection and to take place only after a slow reconstruction process (Brainerd et al., 2009). These findings challenge the view that familiarity is faster and more automatic than recollection.

Understanding whether and how controlled mechanisms support recollection and familiarity is an important endeavor because it may help to explain the divergent developmental trajectories of these two retrieval processes. Various studies have demonstrated that cognitive control only reaches its peak close to adulthood (e.g., Bunge & Wright, 2007; Luna, Padmanabhan, & O'Hearn, 2010), and as such adolescents show lower performance than adults in tasks that require monitoring, inhibition, cognitive flexibility, and decision-making abilities (e.g., Bunge & Wright, 2007; Luna, Marek, Larsen, Tervo-Clemmens, & Chahal, 2015). Even though most researchers agree that such abilities are crucial to successful episodic memory retrieval, few studies have provided clear evidence that the still underdeveloped control abilities during adolescence affect episodic retrieval (Ofen et al., 2007). In fact, as reviewed above, some studies have challenged this proposal by showing no differences between adolescents and adults in recognition memory (Friedman et al., 2010; Ghetti & Angelini, 2008).

To further shed light on the potential differences in context recollection and familiarity from adolescence to adulthood, we investigated whether the use of these mnemonic processes was predicted by different measures of cognitive control. Numerous studies have pointed out the critical role of semantic elaboration by showing that during recollection participants often focus their attention on the semantic features of the past event. Such semantic scope promotes the processing of distinctive features of the event, which in turn may be diagnostic of the prior encounter (Craik & Lockhart, 1972; Dobbins et al., 2002; Raposo, Frade, & Alves, 2016; Raposo, Han, & Dobbins, 2009; Schulman, 1974; Staresina, Gray, & Davachi, 2009). Remarkably, Ghetti and Angelini (2008) demonstrated that the developmental improvement in recollection was restricted to items that had been semantically encoded (as opposed to items that had been perceptually encoded). Conversely, familiarity was not modulated by the nature of the encoding task. These findings indicate that the use of semantic elaboration strategies enhances recollection and that these abilities improve at least until adolescence. Furthermore, during retrieval other cognitive control mechanisms may be critical to an effective recollection (Sprondel et al., 2012; Wagner, 2002). Such mechanisms include monitoring, which allows continuously tracking, evaluating, and adjusting the chosen options, and inhibitory control, which enables the suppression of competing and/or irrelevant information (Luna et al., 2015; Zanolie & Crone, 2018). Although distinct cognitive control abilities develop at different rates, it is widely accepted that they progress at least until adolescence (e.g., Huizinga, Dolan, & van der Molen, 2006; Zanolie & Crone, 2018) and hence may differentially affect recollection in adolescents and adults.

Importantly, the PDP emerges as a useful paradigm not only to disentangle context recollection and familiarity processes in an objective manner but also to inspect the control mechanisms that underlie the two retrieval processes. By manipulating the nature of the encoding tasks (i.e., perceptual vs. semantic), the PDP allows investigating how semantic elaboration strategies differentially affect context recollection and familiarity in the two age groups. It is also useful to directly inspect monitoring and inhibition processes because the exclusion condition requires source monitoring of the studied target material in order to remember the context (i.e., if the word is from List 1) as well as to inhibit the studied nontarget material (i.e., to exclude words from List 2).

In addition to the PDP task, we selected three independent measures of executive functions to investigate whether they predicted the ability to engage context recollection processes. We used the Go/No-Go task (Brocki & Bohlin, 2004) as an index of inhibitory control, the Digit Span as a measure of working memory because this has been reported to be critical in episodic recollection (e.g., Oberauer, 2005; Rhodes et al., 2011), and the semantic verbal fluency task to evaluate the ability to access and search the semantic system (Hurks et al., 2006; Troyer, Moscovitch, & Winocur, 1997) given the levels of processing effect observed in the literature.

Study goals and hypotheses

This study examined the use of context recollection and familiarity processes in adolescents and young adults after semantic and perceptual encoding of words. We relied on the robust PDP to compute context recollection and familiarity estimates and related them to other measures of executive functioning. We hypothesized that, relative to young adults, adolescents would show lower context recollection abilities because cognitive control processes needed for recollection might not yet be fully developed at this age. In contrast, familiarity judgments should be similar across both age groups. Furthermore, if recollection depends on semantic elaboration processes, then the context recollection advantage for adults, relative to adolescents, should be restricted to conditions that promote semantic engagement. Finally, we explored whether the ability to engage recollection processes was predicted by independent measures of executive function, namely inhibitory control, working memory, and semantic fluency.

Method

Participants

Two groups of healthy participants, native speakers of Portuguese, took part in this study. One group consisted of 30 adolescents recruited from public schools (18 female; M_{age} = 13.4 years, range = 13–15), and the other group consisted of 30 young adults recruited from public universities (20 female; M_{age} = 20.6 years, range = 20–22). Of these participants, 3 adolescents and 1 young adult were removed from the analyses due to negative estimates of recollection, which are not interpretable within the PDP (Rouder, Lu, Morey, Sun, & Speckman, 2008) and perhaps reflect lack of attention during the encoding phase. All adults gave informed oral consent. For the adolescents, informed written consent was obtained from their legal guardians. All experimental procedures were approved by the ethics committee of the Faculty of Psychology at the University of Lisbon.

Materials

The study involved four tasks. The main task consisted in an episodic memory recognition paradigm using the PDP (Jacoby, 1991). Three additional tasks, notably the Go/No-Go task, the Digit Span subtest of the Wechsler Adult Intelligence Scale–Third Edition (WAIS-III; Wechsler, 1997) and Wechsler Intelligence Scale for Children–Third Edition (WISC-III; Wechsler, 1991), and a semantic fluency task, complemented the study. For the recognition memory task, the stimuli consisted of a total of 240 Portuguese words distributed across 12 lists of 20 words each (Lists A–L; see Table 1). Words were drawn from Marques, Fonseca, Morais, and Pinto (2007) and Marques (2004) databases. All were concrete nouns, with 4 to 10 letters, and had an age of acquisition under 10 years. Words across the different lists were matched in age of acquisition, number of letters, familiarity, written logarithmic frequency, vividness, and alphabetic order between the first and last letters of each word (with $p > .05$ in all cases). For the Go/No-Go task, we developed a computerized version of this task closely following the one used by Brocki and Bohlin (2004), in which a total of 100 items were presented, 75 corresponding to Go items and 25 to No-Go items. For the Digit Span subtest and the semantic fluency task, we followed Wechsler (1991, 1997) and Troyer et al. (1997), respectively.

Procedure

All participants were tested individually, with the adolescents being tested in a quiet room at their school and the young adults at the experimental psychology laboratories of the Faculty of Psychology

Table 1
Mean proportions (and standard deviations) of the variables matched across the 12 lists of words (A–L; 20 words each) used in the recognition memory paradigm.

	Age of acquisition[a]		Number of letters[b]		Familiarity[c]		Written logarithmic frequency[d]		Living/ nonliving[e]	Alphabetic order between first and last letters[e]
List										
A	3.49	(1.49)	6.85	(1.98)	2.01	(0.69)	2.13	(0.79)	.60	.40
B	3.79	(0.90)	6.95	(1.99)	2.02	(0.48)	2.23	(0.68)	.60	.50
C	3.55	(0.89)	6.85	(1.98)	2.11	(0.52)	2.17	(0.52)	.55	.50
D	3.00	(0.82)	6.90	(2.02)	2.04	(0.56)	2.29	(0.74)	.50	.45
E	3.09	(0.78)	6.95	(1.82)	2.03	(0.45)	2.15	(0.78)	.55	.55
F	3.22	(0.93)	6.75	(2.07)	2.19	(0.56)	2.07	(0.74)	.50	.50
G	3.13	(0.70)	6.80	(1.94)	1.99	(0.54)	2.22	(0.71)	.55	.50
H	3.07	(0.58)	6.95	(1.82)	2.09	(0.45)	2.04	(0.44)	.55	.50
I	2.97	(0.65)	6.80	(1.94)	2.03	(0.47)	2.23	(0.70)	.55	.45
J	3.01	(1.25)	6.80	(1.99)	1.99	(0.79)	2.17	(0.79)	.45	.40
K	3.06	(1.03)	6.90	(2.05)	2.04	(0.57)	2.16	(0.70)	.60	.40
L	2.94	(1.19)	6.65	(1.95)	2.04	(0.56)	2.18	(0.78)	.45	.40

[a] Each point from the 8-point age of acquisition scale represent one age band, meaning that words were learned at the age of (1) 0–2 years, (2) 3–4 years, (3) 5–6 years, (4) 7–8 years, (5) 9–10 years, (6) 11–12 years, (7) 13 or more years, or (8) adulthood (Marques et al., 2007).
[b] Number of letters varied from 4 to 10.
[c] Familiarity ranged from 1 = *highly familiar* to 5 = *very unfamiliar.*
[d] Written logarithmic frequency varied from 0 to 4.34.
[e] Living/nonliving category and alphabetic order between first and last letters are represented by the proportion of binary values of 1 (living or alphabetic order) and 0 (nonliving or nonalphabetic order).

at the University of Lisbon. The experimental protocol was conducted in the following order: two encoding retrieval cycles of the recognition memory task, Digit Span subtest, semantic fluency task, another two encoding retrieval cycles of the recognition memory task, and the Go/No-Go task. Total duration was approximately 1 h.

Recognition memory task

Each participant underwent four encoding retrieval cycles (see Table 2). During encoding, participants studied two sequential lists of single written words in either a semantic or perceptual manner. In the semantic encoding condition, for a given list (of 20 words) participants needed to decide about the concept's pleasantness (i.e., is this concept pleasant?), whereas for another list they needed to decide about the concept's living/nonliving category (i.e., is this concept a living thing?). In the perceptual encoding condition, for one list participants made a number of letter judgment (i.e., does the word have seven or more letters?), whereas for the other list participants made an alphabetic order decision (i.e., are the first and last letters in alphabetical order?). Each encoding trial began with a fixation cross for 500 ms, followed by the presentation of the word and the encoding question for 3000 ms, during which time participants needed to respond by pressing a key for "yes" and another key for "no" using the left index and middle fingers, respectively. A 500-ms blank screen was used as the intertrial interval. Immediately after each encoding condition, a memory recognition test was administered. Participants were presented with 60 single words that either were taken from the previous two encoding lists (20 old words from the first list and 20 old words from the second list) or were new words (20 words that had not been presented during encoding). In the inclusion condition, participants indicated whether each word had been presented before or not (i.e., is the word old?). In the exclusion condition, participants were asked whether the word had been presented in the first encoding list or not (i.e., is the word from List 1?). Thus, whereas in the inclusion condition participants needed to recognize all old words and reject new ones, in the exclusion condition they needed to recognize words from the first encoding list and reject words from the second list and new words. Each trial began with a fixation cross for 500 ms, followed by the presentation of the word and the retrieval question for 4000 ms, during which time participants responded by pressing a key for "yes" and another key for

Table 2
Encoding questions, retrieval questions, and correct responses for the four encoding retrieval cycles of the recognition memory task.

	Encoding Questions	Retrieval Questions	Correct responses
Inclusion			
Semantic	L1: living? L2: pleasant?	Old?	"yes" (L1 and L2), "no" (New)
Perceptual	L1: alphabetic order? L2: 7 or more letters?	Old?	"yes" (L1 and L2), "no" (New)
Exclusion			
Semantic	L1: living? L2: pleasant?	List 1?	"yes" (L1), "no" (L2 and New)
Perceptual	L1: alphabetic order? L2: 7 or more letters?	List 1?	"yes" (L1), "no" (L2 and New)

Note. L1, List 1; L2, List 2; New, new words list.

"no" using the left index and middle fingers, respectively. Trials were separated by a 500-ms blank screen. The order of the cycles, of the encoding tasks, and of the lists of words inside each cycle was counterbalanced across participants.

Go/No-Go task

Participants were instructed to answer as quickly as possible by pressing a key with the index finger of the dominant hand every time a Go stimulus was presented (i.e., a square with an X, a square with a short vertical line in the middle, a square with a diagonal to the right, and a square with a diagonal to the left) and to inhibit the response (by not pressing any button) when a No-Go stimulus appeared (i.e., a square with a long vertical line in the middle). Each stimulus was presented for 460 ms, and the interval between stimuli was jittered from 2550 to 2783 ms. Items were presented in a pseudorandom order with the restriction that no more than 3 consecutive trials were the same figure and the first 21 trials were Go stimuli, creating an initial dominant response (as in Brocki & Bohlin, 2004).

Digit Span subtest

The experimenter read aloud sequences of digits, starting with sequences of two digits until nine digits, at the speed of 1 s per digit. Participants repeated each of the sequences immediately after the experimenter had read it in the same order (Digit Span forward) or in the reverse order (Digit Span backward). For each number of digits, there were two different sequences, and the task finished when participants failed both sequences for the same number of digits. For the final score, 2 points were given if both sequences were repeated correctly and 1 point if the participant failed to repeat one of them.

Semantic fluency task

Participants needed to freely generate as many animals as possible within a time constraint of 1 min. For each participant, four different scores were calculated: the total number of words produced (excluding repetitions), the relative number of clusters generated, the relative number of isolated words not included in any cluster (including repetitions), and the relative number of switches between clusters and/or isolated words (including repetitions). The relative values were obtained by dividing the absolute value by the total number of words produced. Following Troyer et al. (1997), we considered clusters as groups of words belonging to the same semantic subcategory. These semantic patterns were determined after participants had generated the words without a previously defined scheme. In addition, according to the same authors, items belonging to more than one category were assigned to both categories except when all items of two categories could be assigned to a single larger category. The same was done for smaller clusters emerging inside larger ones, in which case the larger cluster was the one considered. Clusters, switches, and isolated words all were organized and scored a posteriori by an agreement between two independent judges.

Presentation and timing of stimuli for the recognition memory task and the Go/No-Go task were controlled using E-Prime software (Psychology Software Tools, Sharpsburg, PA, USA); responses to the Digit Span subtest and the semantic fluency task were registered by the experimenter.

Statistical analyses

The analyses of the episodic memory task focused on the retrieval phase. First, we investigated age-related differences on the proportion of "yes" responses (hits and false alarms) across the different experimental conditions. Then, the estimates of recollection and familiarity were calculated. As mentioned above, the estimation of the proportion of recollection (R) and familiarity (F) processes is based on the "yes" responses in the inclusion and exclusion conditions:

$$R = \text{hits (of the inclusion condition)} - \text{false alarms (of the exclusion condition)};$$

$$F = \text{false alarms (of the exclusion condition)}/(1 - R)$$

Recollection and familiarity processes' estimates were based on the performance of List 2 items because this is the only list that originates both hits and false alarms in the inclusion and exclusion conditions, respectively. The proportion of "yes" responses and proportion of recollection and familiarity processes were then analyzed in separate analyses of variance (ANOVAs).

To investigate age-related differences in the complementary tasks, we conducted independent-sample t tests. To explore whether performance in these tasks predicted performance in the main episodic memory task, we carried out a hierarchical multiple regression. This analysis tested two models. Model 1 used participants' age as the predictor and memory performance as the dependent measure. Model 2 included performance in the complementary tasks as the additional predictors. Due to the limited number of participants, we considered a maximum of one predictor per complementary task.

Statistical analyses were performed with SPSS Statistics software Version 23 (IBM Corp., Armonk, NY, USA). The data are available at Mendeley Data (Andrade and Raposo, 2020).

Results

Hits and false-alarms

We first analyzed the proportion of "yes" responses to ensure that participants discriminated old and new items successfully in the different tasks. Mean proportions of "yes" responses during the retrieval phase of the recognition memory paradigm as a function of age group (adolescents or young adults), retrieval condition (inclusion or exclusion), level of processing (semantic or perceptual encoding), and words' origin (List 1, List 2, or new) are shown in Table 3. In the inclusion condition, the proportion of "yes" responses to encoded items corresponds to hit rates, whereas the proportion of "yes" responses to new items corresponds to false alarms. In the exclusion condition, the proportion of "yes" responses to items encoded in List 1 corresponds to the hit rate, whereas the proportion of "yes" responses to items encoded in List 2 and new items reflects false alarm rates.

We conducted separate mixed-design ANOVAs on the proportion of "yes" responses in each retrieval condition (semantic inclusion, perceptual inclusion, semantic exclusion, and perceptual exclusion), with age group as a between-participants factor and word's origin (List 1, List 2, or new) as a within-participants factor.

In the four retrieval conditions, there was a main effect of word's origin ($F > 170.95$, $p < .001$, $\eta_p^2 > .76$ in all cases), with a significant lower proportion of "yes" responses to new words than to words from List 1 or List 2, which demonstrates that participants successfully discriminated between previously encoded and new items. There was no main effect of age group ($ps > .05$). Yet, we found a significant interaction between age group and word's origin for the semantic conditions only ($F > 4.40$, $p < .015$, $\eta_p^2 > .08$ in both cases). In the semantic inclusion condition, whereas for adults there was no

Table 3
Mean proportions (and standard deviations) of "yes" responses in each experimental condition for adolescents and young adults.

	Adolescents	Young adults
Inclusion		
Semantic		
L1: hits	.84 (.13)	.91 (.08)
L2: hits	.90 (.12)	.94 (.07)
New: false alarms	.09 (.12)	.07 (.07)
Perceptual		
L1: hits	.57 (.20)	.59 (.16)
L2: hits	.72 (.15)	.77 (.14)
New: false alarms	.12 (.10)	.17 (.12)
Exclusion		
Semantic		
L1: hits	.77 (.13)	.83 (.12)
L2: false alarms	.28 (.14)	.17 (.12)
New: false alarms	.05 (.06)	.05 (.09)
Perceptual		
L1: hits	.54 (.14)	.60 (.17)
L2: false alarms	.42 (.12)	.45 (.13)
New: false alarms	.19 (.13)	.16 (.12)

Note. L1, List 1; L2, List 2; New, new words list.

difference in the proportion of "yes" responses between List 1 and List 2 words, adolescents gave significantly more "yes" answers to List 2 words than to List 1 words, perhaps reflecting a recency effect. In the semantic exclusion condition, adolescents provided more incorrect "yes" responses than adults to List 2 words, $t(54) = 3.13$, $p = .003$, $d = 0.85$, whereas there were no age differences for List 1 or new words ($ps > .05$). This suggests that adolescents were more susceptible to List 2 intrusion errors than adults.

We then conducted a mixed-design ANOVA on the new items only, with age group (adolescents or young adults) as a between-participants factor and retrieval condition (inclusion or exclusion) as a within-participants factor. This analysis did not reveal significant effects ($ps > .05$). This is important because an equivalent false alarm rate to new words in the inclusion and exclusion conditions suggests that there was no shift in response criterion from inclusion to exclusion tasks or vice versa, a key assumption of the PDP (Jacoby et al., 1993; Yonelinas, 2002; Yonelinas & Jacoby, 2012).

Recollection and familiarity parameters

The estimates of context recollection and familiarity processes for each age group and processing level are shown in Fig. 1. A mixed-design ANOVA was conducted, with the PDP estimates (recollection or familiarity) and level of processing (semantic or perceptual) as within-participants factors and age group (adolescents or young adults) as a between-participants factor.

We found a main effect of PDP estimates, $F(1, 54) = 67.55$, $p < .001$, $\eta^2_p = .56$, associated with an overall higher recruitment of familiarity processes ($M = .71$, $SD = .17$) than context recollection processes ($M = .50$, $SD = .11$). There was also a main effect of level of processing, $F(1, 54) = 114.56$, $p < .001$, $\eta^2_p = .68$, with higher retrieval of items semantically encoded ($M = .73$, $SD = .15$) than perceptually encoded ($M = .48$, $SD = .13$). A main effect of age group was also found, $F(1, 54) = 5.18$, $p = .027$, $\eta^2_p = .09$, with adolescents having lower retrieval performance ($M = .57$, $SD = .11$) than young adults ($M = .64$, $SD = .11$). In addition, a significant interaction between PDP estimates and levels of processing was found, $F(1, 54) = 52.16$, $p < .001$, $\eta^2_p = .49$. Paired-sample t tests showed that whereas for semantically encoded items participants used similar levels of familiarity ($M = .77$, $SD = .24$) and context recollection processes ($M = .70$, $SD = .16$), $p > .05$, for items perceptually encoded the use of context recollection processes ($M = .31$, $SD = .16$) was significantly lower than the use of familiarity

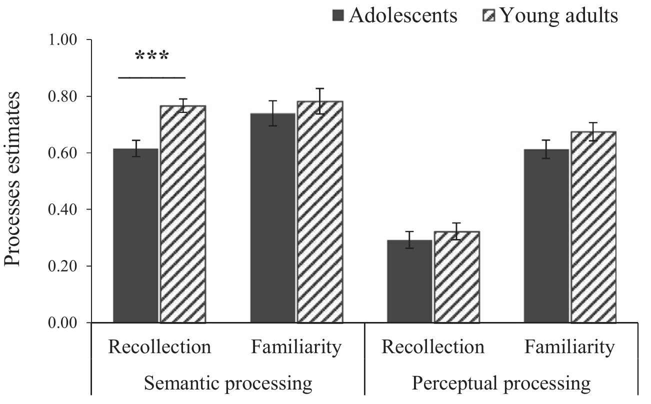

Fig. 1. Mean estimates of context recollection and familiarity processes in both semantic and perceptual processing conditions for adolescents and young adults. Error bars represent standard error of the mean. $^{***}p < .001$.

processes (M = .65, SD = .17), $t(55)$ = 13.37, p < .001, d = 1.79. Most important, we found a triple interaction among PDP estimates, level of processing, and age group, $F(1, 54)$ = 4.18, p = .046, η^2_p = .07. Independent-sample t tests revealed a significantly lower recruitment of context recollection processes for adolescents (M = .62, SD = .16) than for adults (M = .77, SD = .13) in the semantic condition only, $t(54)$ = 3.98, p < .001, d = 1.03. In contrast, there were no significant age-related differences in the level of context recollection for perceptual processing or in the degree of familiarity for semantic and perceptual processing conditions (p > .05 for all three cases).

Complementary measures

Table 4 illustrates participants' mean performance in the three complementary tasks. For each measure, an independent-sample t test was run between adolescents and young adults. In the Go/No-Go task, the error rate was significantly higher for adolescents than for young adults in the case of both commission errors, $t(54)$ = 3.88, p < .001, d = 1.00, and omission errors, $t(54)$ = 2.36, p = .022, d = 0.59. In the Digit Span subtest, whereas we found no difference between the two age groups in the forward order task (p > .05), adults performed significantly better than adolescents in the reverse order task, $t(54)$ = 2.18, p = .033, d = 0.58. The semantic fluency task revealed no significant differences between age groups in any measure (p > .05 in all cases).

Subsequently, we investigated the extent to which performance in these tasks and participants' age predicted context recollection in the semantic condition (found to differ between the two age groups). To this end, we conducted a hierarchical multiple regression analysis including all participants (N = 56). Model 1 included as a predictor the participants' age (the main demographic measure in this study). Model 2 included a predictor from each complementary task: the proportion of commission errors in the Go/No-Go task (which indexes inhibitory control), the backward score of the Digit Span subtest (which assesses working memory abilities), and the total number of words generated in the semantic fluency task (a measure of verbal fluency performance). Note that the other measures were not inserted as predictors due to the limited number of participants and in order to avoid multicollinearity effects. The data met the basic assumptions required for this type of analysis, namely no multicollinearity among the model's predictors (age: tolerance = .72, variance inflation factor [VIF] = 1.39; commission errors: tolerance = .79, VIF = 1.26; backward score: tolerance = .88, VIF = 1.13; total number of words: tolerance = .94, VIF = 1.07). The three executive measures considered were not intercorrelated (rs < .17, ps > .05). Table 5 shows the parameters of the regression model. The results revealed that in the first model participants' age explained 23% of the variance found in context recollection for the semantic condition [Model 1: $R_a{}^2$ = .23, $F(1, 54)$ = 17.71, p < .001]. Adding the other three predictors improved the model's adjustment, explaining an addi-

Table 4
Mean performances (and standard deviations) in the three complementary tasks: Proportions of omission and commission errors from the Go/No-Go task; forward and backward scores from the Digit Span subtest; and total numbers of words, relative numbers of clusters, relative numbers of isolated words not included in any cluster, and relative numbers of switches between clusters and/or isolated words from the semantic fluency task.

	Adolescents	Young adults
Go/No-Go task		
Omission errors	.35 (.17)	.27 (.09)
Commission errors	.35 (.21)	.18 (.12)
Digit Span subtest		
Forward score	8.9 (1.6)	9.6 (2.1)
Backward score	6.4 (1.2)	7.4 (2.1)
Semantic fluency task		
Number of words–absolute	20.7 (2.5)	22.3 (4.5)
Number of clusters–relative	.26 (.08)	.25 (.06)
Number of isolated words–relative	.13 (.11)	.17 (.11)
Number of switches–relative	.34 (.12)	.37 (.11)

Table 5
Hierarchical multiple regression models used to predict the level of context recollection in the semantic processing condition of the episodic memory task.

	Recollection in the semantic condition					
	Model 1			Model 2		
	B (*SE*)	*β*	*p*	*B* (*SE*)	*β*	*p*
Predictors						
Age	.022 (.005)	.497	<.001	.012 (.006)	.268	.043
Commission errors (Go/No-Go task)				−.292 (.108)	−.332	.009
Backward score (Digit Span subtest)				.014 (.011)	.153	.194
Total number of words (semantic fluency task)				.007 (.005)	.152	.185
R_a^2	.233			.339		
F	17.711		<.001	8.056		<.001
ΔR_a^2				.106		
ΔF				3.890		

Note. N = 56. Predictors included participants' age (Model 1) and three additional performance measures from the complementary tasks (Model 2).

tional 11% of the variance [Model 2: R_a^2 = .34, $F(4, 51)$ = 8.06, p < .001]. Besides age, the proportion of commission errors significantly predicted our dependent variable (B = − .29, SE = .11, p = .009), explaining about 9% of the variance.

Discussion

We investigated context recollection and familiarity processes in recognition memory in adolescents and young adults and asked whether cognitive control mechanisms could support, at least in part, differences in memory abilities between the two age groups. For this purpose, the PDP was applied to a word recognition memory task, which allowed teasing apart the contribution of context recollection and familiarity components of memory without relying on participants' metamemory abilities.

Relative to young adults, adolescents showed lower episodic memory performance only when the task required context recollection of semantically encoded material. Several studies on dual-process recognition memory have demonstrated that recollection is strongly dependent on semantically rich encoding. In contrast, familiarity has been referred to as more automatic and less dependent on the level of processing at encoding (Mandler, 1980; Tulving, 1985; Yonelinas, 2002). Following this view, our findings indicate that the ability to engage in such elaborative processing might not yet be fully developed during adolescence, which may hinder context recollection in this group relative to young adults. This proposal is in line with the results of Ofen et al. (2007), who showed that recollection increases until adulthood. It is also in agreement with the work by Ghetti and Angelini (2008), who argued that semantic processing plays a crucial role in the late development of recollection. This interdependency between semantic elaboration and recollection has been supported by fMRI studies showing that although both processes are distinct, they require cognitive control and depend on similar structures of the PFC (e.g., Han, O'Connor, Eslick, & Dobbins, 2012; Raposo et al., 2009). Importantly, the PFC undergoes a substantial decrease in volume and synaptic pruning during adolescence (Gogtay et al., 2004; Sowell, Thompson, Tessner, & Toga, 2001), which has been associated with the protracted maturation of working memory (Satterthwaite et al., 2013) and increasing levels of cognitive and emotional regulation (Gee et al., 2013; Shaw et al., 2006). Thus, it is plausible that the late maturation of the PFC underlies age-related differences in the recollection of contextual details of semantically encoded material. To the best of our knowledge, our study is the first to show a clear-cut distinction in context recollection abilities between adolescents and adults and to show that this dissociation may depend on the development of semantic elaboration skills.

When the encoding task did not require semantic elaboration (i.e., during perceptual encoding), the recruitment of context recollection processes was substantially lower in both groups and no age-related differences were found. This converges on the idea that shallow encoding hampers memory recognition and the retrieval of items' distinctive features, even in adults (e.g., Gallo, Meadow, Johnson, & Foster, 2008; Yonelinas, 2002). Note that although context recollection was low after perceptual encoding, participants did not abandon the task of trying to retrieve contextual information (i.e., the word's list). If that were the case, then for old words participants would be responding at chance, guessing which words were from List 1 and which ones were not. Yet, this did not occur; in the perceptual exclusion condition, the proportion of "yes" responses to List 1 words was significantly higher than the proportion of "yes" responses to List 2 words in both age groups. This indicates that participants did not base their responses solely on familiarity but instead used some degree of context recollection to respond to the perceptual exclusion task.

Turning to familiarity-based responses, adolescents and young adults yielded similar results. This is consistent with the notion that the development of this process stabilizes earlier during childhood (for a review, see Ghetti & Lee, 2014), a finding that has been replicated in recognition memory studies using the PDP (e.g., Anooshian, 1999), the remember–know paradigm (e.g., Billingsley et al., 2002; Ofen et al., 2007), the ROC procedure (e.g., Ghetti & Angelini, 2008), and the conjoint recognition procedure (e.g., Brainerd et al., 2004). Overall, familiarity was higher for semantically encoded items than for perceptually encoded items, as reported in prior work (Yonelinas, 2002). Importantly, the relative difference across the two age groups was similar in the two encoding conditions, as previously demonstrated by Ghetti and Angelini (2008). This suggests that the development of familiarity does not depend on semantic elaboration skills. Because familiarity reflects lower or more superficial levels of information detail (Yonelinas, 2002), it is reasonable that, when compared with recollection, familiarity depends less on the type of material that is being retrieved or how it was initially encoded.

Our findings differ from those of Odegard et al. (2008) who implemented the conjoint recognition procedure in a group of 11-year-olds and a group of adults and estimated parameters of familiarity, context recollection, and target recollection. Unlike the current research, they found different levels of familiarity across age groups. Moreover, no increase in context recollection from older children to adults was observed; instead, there was an improvement of target recollection. Differences between our paradigm and their paradigm may explain the divergent findings. First, the PDP only allows measuring context recollection and familiarity but not target recollection. It is unclear how the estimation of another type of recollection would affect our results. Second, whereas our paradigm examined correct recognition of target words, Odegard et al. (2008) focused on false/illusory recognition (namely to obtain the context recollection estimate), which may entail different processes and phenomenological experiences. Third, our study tested adolescents (13–15 years of age), whereas Odegard et al. (2008) tested 11-year-old children. As mentioned earlier, these age differences (adolescents vs. older children) may have important implications for the results. Clearly, more research with adolescents is needed to explore the specific developmental trajectories of both types of recollection and familiarity and to clarify how the different estimation methods may affect the results.

Even though the PDP paradigm adopted in this study was firmly based on the dual-process account, other models of memory development have been put forward. Of note, the two-component framework of Shing and colleagues (Shing et al., 2010; Shing, Werkle-Bergner, Li, & Lindenberger, 2008) advocates for a duality between an associative component responsible for the binding of the distinct features of an episodic representation and a strategic component that allows controlling memory processes at both encoding and retrieval stages. It has been proposed that the first component, viewed as more automatic, matures during childhood, whereas the second component reaches maturation later, close to young adulthood (Shing et al., 2008). Interestingly, the authors have argued that an important encoding strategy that promotes memory control is the use of semantic knowledge to integrate various aspects of a memory trace (Shing et al., 2010), as found in our data. Alternatively, according to the source monitoring framework (Johnson, Hashtroudi, & Lindsay, 1993), the strength of a memory trace is viewed as a continuum, depending on the number and quality of features (e.g., perceptual, semantic) bound to an event representation. Critically, however, the ability to monitor specific contextual information associated with a memory trace (e.g., determining whether a word appeared in List 1) is hindered in children when compared with adults (Cycowicz, Friedman, Snodgrass, & Duff, 2001; for a review, see Raj & Bell, 2010). Although our study was not designed to disentangle these alternative explanations, our results can be reasonably integrated with these views. Importantly, as presented at the outset, the dual-recollection model proposed by Brainerd et al. (2014, 2015) makes the distinction between target and context recollection. Like our study, most recognition memory research has only examined context recollection, but recollection may occur even if participants do not remember the specific contextual details being probed. For that reason, further examining target recollection and its interaction with age is a fundamental future goal.

Most accounts of recognition memory propose that the developmental dissociation between recollection and familiarity lies in the differential need for cognitive control, which presents protracted development. Indeed, as expected, performance of adolescents and young adults differed in two measures of cognitive control—inhibitory control and working memory (Diamond, 2013)—which are still underdeveloped before reaching adulthood (Luna et al., 2015). Of importance, recollection of contextual details of semantically encoded items depended on individual differences in inhibitory control. Beyond age, which came up as the main explanatory variable, inhibitory control significantly explained part of the variance found between adolescents and adults. Specifically, participants who engaged less in commission errors in the Go/No-Go task demonstrated greater ability to recollect contextual details of semantically encoded items. Presumably, a relevant factor in successfully determining an item's origin (as required by the exclusion task) is the ability to inhibit a preponderant but incorrect response, that is, the propensity to attribute to List 1 an old item that comes from List 2. As such, inhibitory control may lead to lower intrusion rates, improving context recollection. Thus, this study supports the view that context recollection depends on controlled processes, at least in recognition tasks. Along the same vein, Picard, Cousin, Guillery-Girard, Eustache, and Piolino (2012) showed that executive functions, notably inhibition and flexibility, were reliable predictors of correct retrieval of contextual information.

Regarding performance in the semantic verbal fluency task, no differences were found between age groups, nor did it arise as a predictor of recollection of semantic material. There is evidence that semantic knowledge increases over the course of childhood and adolescence (e.g., Bjorklund & Jacobs, 1985; McRae, Khalkhali, & Hare, 2012). Thus, the lack of age-related differences in our study might denote the need for a more fine-grained measure of semantic knowledge. In the interest of time, we only tested fluency for animals, which might not be sensitive enough to capture differences in semantic processing. On the other hand, some research has suggested that the structure of the semantic system is already fully developed during adolescence (Robertson & Köhler, 2007), which could explain the similar pattern across groups. Given the critical finding that the ability to strategically use semantic knowledge to improve recollection is yet underdeveloped in adolescents, the extent of and access to semantic information in adolescents deserves further research.

The restricted sample size of our study is a potential limitation, and future studies should take that into account in order to avoid difficulties of replication. Still, the current investigation served as a validation of the PDP as a suitable experimental paradigm to estimate context recollection and familiarity processes in a developmental perspective. The fact that all participants successfully discriminated between previously studied and new items, and did not shift the response criterion between inclusion and exclusion conditions (a key assumption of the PDP), indicates that the paradigm is appropriate to implement with adolescents. This is important because the contradictory findings observed during adolescence (e.g., Ghetti & Angelini, 2008; Friedman et al., 2010; Ofen et al., 2007) may be due to the methodology used given that in those studies the estimation of recollection depended on participants' self-report or metamemory decisions (e.g., confidence ratings, remember–know decisions). Because metamemory is still under development during adolescence (Fandakova et al., 2017), the use of measures that require introspection might not accurately track retrieval differences between adolescents and adults, which are necessarily smaller and more specific than those between childhood and adulthood. Because adolescence can be seen as a continuum toward adulthood (Sawyer, Azzopardi, Wickremarathne, & Patton, 2018), capturing subtle differences between close age groups requires selecting the most appropriate and sensitive paradigm.

Conclusion

Studying episodic memory retrieval during adolescence using the PDP paradigm has provided novel evidence on how context recollection and familiarity develop and how the two memory components are differentially affected by semantic processing. Our results are in line with solid evidence for a dissociation between recollection and familiarity throughout development, but importantly, we extend this finding to the adolescent period. We propose that semantic elaboration abilities underlie the age-related differences in context recollection. In addition, the data point to inhibitory control as a crucial mechanism supporting context recollection abilities.

CRediT authorship contribution statement

Miguel Ângelo Andrade: Conceptualization, Methodology, Software, Formal analysis, Investigation, Resources, Writing - original draft, Writing - review & editing, Funding acquisition. **Ana Raposo:** Conceptualization, Methodology, Resources, Writing - review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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