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Ontogeny of the Proactive Interference Effect in Visual Short-term Memory

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Abstract

Introduction. The processes of information selection and memorisation undergo changes during ontogeny of the controlling functional systems of the brain, including the formation of inhibitory control associated with the organisation of proactive interference. The *aim of the* present study was to investigate the regularities of changes in the volume of memorisation of visually presented information at different stages of ontogeny (in the age range from 5 to 78 years) due to both the action of proactive interference and the activity of learning in the process of reproduction during testing. **Methods.** A total of 563 participants, including preschool and school-aged children, students, and retired people, took part in the study. To investigate inhibitory functions in memory processes, a computerised technique was used to study the memorisation of the same set of visual stimuli presented in different order in three series. A new series was started after the subject made an error in the previous series. **Results.** Nonlinear changes of proactive interference (RIF) during the reproduction of visual information in ontogeny were found: proactive interference is less pronounced at preschool age, reaches its maximum expression in students at the age of 20 years and remains at a high level in the elderly when the volume of reproduced material decreases. Comparison of proactive interference in people with different memory productivity revealed that the expression of proactive interference is higher at high productivity levels regardless of age and interference is insignificant in people with low memory productivity. Relationship of interference with gender was found only in preschool and junior high school age: proactive interference is higher in girls. possibly due to the speed of brain maturation in this age range in boys and girls. **Discussion.** It is shown that the critical period for the formation of proactive interference is the age range of 6-8 years, when the severity of interference depends on gender, which is probably due to the conditions of brain maturation in boys and girls. Proactive interference reaches its highest expression in students at the age of 20 and then gradually decreases in old age.

Keywords

Short-term memory, ontogeny, proactive interference, memory learning, inhibitory functions

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Introduction

Inhibitory functions as components of executive control of information memorisation behaviour can manifest in proactive interference (Bari & Robbins, 2013; Luna, Marek, Larsen, Tervo-Clemmens & Chahal, 2015). Proactive interference has previously been shown to dominate the temporal dynamics of remembering visually presented information in groups of both twenty- and sixty-year-old study participants. However, the organisation of cognitive functions (attention and intelligence) differs depending on age and the preferred memorisation strategy: the effect of forgetting induced by reproduction or learning to remember during testing (Razumnikova, 2019).

The Retrieval-Induced Forgetting (RIF) effect (Anderson, 2003; Murayama, Miyatsu, Buchli, & Storm, 2014) is an impairment in reproduction due to proactive interference of remembered information, or impaired executive control of retrieval of a memory trace (Anderson, Reinholz, Kuhl, & Mayr, 2011; Aslan & Bauml, 2011; Rowland, 2014). Greater RIF reflects effective inhibitory functions (Noreen & MacLeod, 2015).

The early stages of ontogeny are characterised by the development of inhibitory functions as a consequence of myelination of nerve fibres and the formation of functional connections of the prefrontal cortex when organising purposeful behaviour (Razumnikova, Nikolaeva, 2021). In preschool children, the temporal dynamics of this process varies significantly depending on their genetic features and educational conditions (Nikolaeva, 2010). The efficiency of formation of inhibitory functions and executive control at early stages of Ontogeny is considered as the basis for successful schooling of children (Ribner, Willoughby & Blair, 2017; Sánchez-Pérez et al., 2017) and as a predictor of high intelligence and social status in the future (Moffitt et al., 2011).

Late stages of ontogeny are characterised by a weakening of inhibitory functions, which is associated with memory impairment in ageing (Collette, Schmidt, Scherrer, Adam & Salmon, 2009; Healey, Hasher & Campbell, 2013). Moreover, more pronounced RIF in older adults is accompanied by better executive control of attention (Razumnikova, 2019; Razumnikova, Nikolaeva, 2019), which may reflect the relative preservation of inhibitory functions as a cognitive resource of "successful" aging.

The observed diversity in the dynamics of cognitive performance decline in older adults has been attributed to a complex set of changes in inhibitory control, working memory and speed of mental operations, each characterised by an individual age-related trajectory (Grégoire, Rivalan, Le Moine & Dellu-Hagedorn, 2012; Rozas, Juncos-Rabadán & GonzáGonzález, 2008; Sylvain-Roy, Lungu & Belleville, 2015).

The purpose of the present study was to investigate the patterns of ontogeny of remembering visually presented information across a wide age range from 5 to 78 years using a model of memory formation that incorporates the effects of forgetting induced by playback or learning to remember during testing.

Methods

Test subjects

There were 563 participants in the study, of which:

- 89 preschool-aged children (GrPG);
- 56 junior school students (GrJSc);
- 64 Middle-aged school children (GrMASc);
- 37 adolescent high school students (GrAHSc);
- 193 twenty-year-old students (GrS);
- 124 people of retirement age (GrPRA).

Adult participants of the study or parents of children were familiarised with the conditions of testing and gave informed consent for testing. The study was approved by the Ethical Committees of the NSTU CSF and Herzen State University of Russia.

For comparative analysis of changes in memory indices, 6 age groups were identified, the numerical composition of which is shown in Table 1.

Table 1
Age characteristics of the six groups studied

Group	Quantity		Age (years)
	Men	Women	
Preschoolers (GrPG)	38	51	5,7 ± 0,4
Junior school students (GrJSc)	27	29	7,6 ± 0,4
Middle-aged school children (GrMASc)	31	33	10,9 ± 0,4
High school students (GrAHSc)	16	21	14,2 ± 0,6
Students (GrS)	49	144	20,0 ± 0,3
People of retirement age (GrPRA)	34	90	62,6 ± 0,3

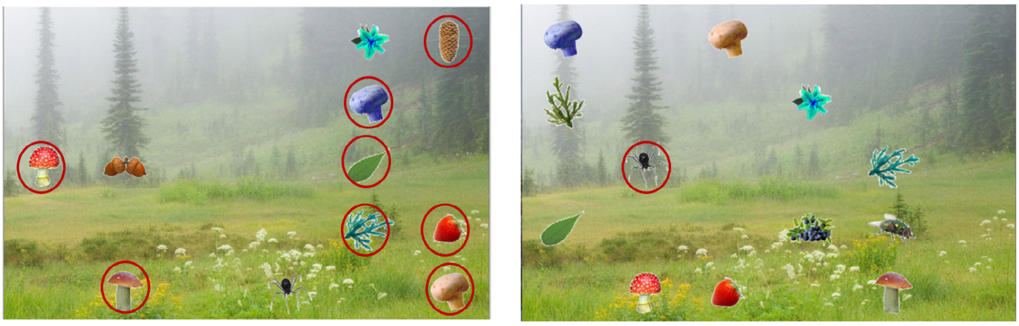
Research methodology

To investigate inhibitory functions (proactive interference) in memory processes, we used a ***computerised technique of memorising visual stimuli***: objects of wildlife of different categories, different colours and different spatial arrangements.

At the first presentation, three stimuli randomly selected from a set of 30 objects appeared on the screen. The instruction was to select any one of them by marking it with the mouse cursor. Subsequently, at each new presentation, one new stimulus was added, while the instruction for the subject remained the same: to mark the stimulus that had not been previously selected (Razumnikova and Savinykh, 2016).

Figure 1 shows an example with the presentation of 11 stimuli with eight stimuli previously marked for memorisation, with the next presentation marking one of the new stimuli. When the same, already selected object was pressed again, the first series of testing ended and the next one began with the presentation of the same objects, but in a different random sequence. A total of three test series were used.

Figure 1
An example of stimuli presented during a visual memory test (on the left, circles indicate those that have been selected; on the right, a new stimulus)



Statistica 13.3.1 Ru AXA805I391121ARCN5-S software package was used for statistical analysis of recall rates.

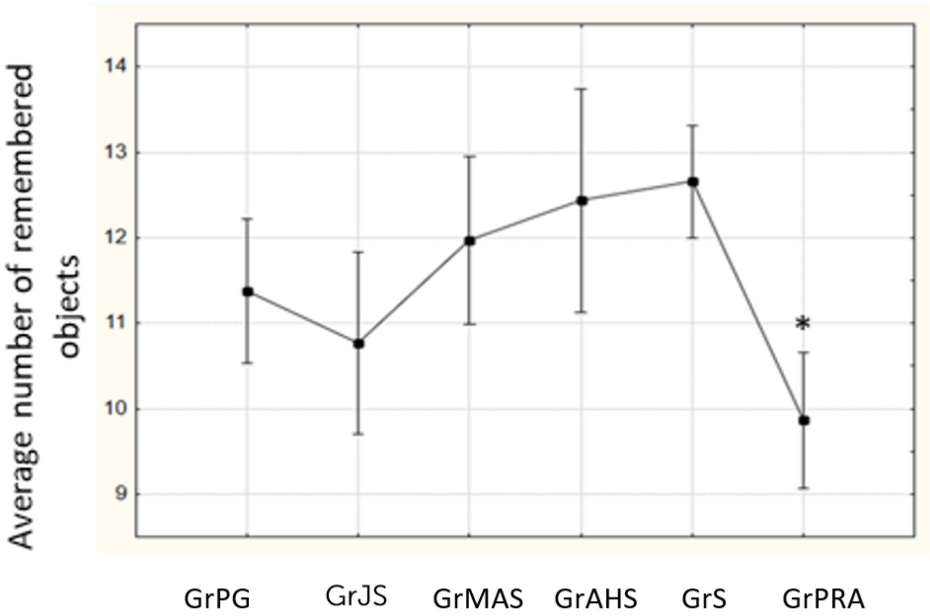
Results

Age-related features of short-term visual memory as a reflection of the effect of proactive interference

To find out possible individual changes in the dynamics of memory performance during repeated stimulus presentation, we used analysis of variance (two-factor ANOVA with repeated measures) with the factors AGE (6), GENDER (2), and the dependent variable SERIES (3). A significant effect was found for the factor AGE ($F_{5,547}$ = 6.69; p < 0.000005; η^2 = 0.06) due to lower reproduction values in the people of retirement age (in GrPRA) compared to the other groups, with significant differences with students and schoolchildren over 11 years of age (GrS, GrAHSc and GrMASc) (Figure 2). At the same time, the best average memory scores were observed in older schoolchildren (GrAHSc) and students (GrS).

Figure 2

Age-related changes in mean values of visual short-term memory reproduction in six groups



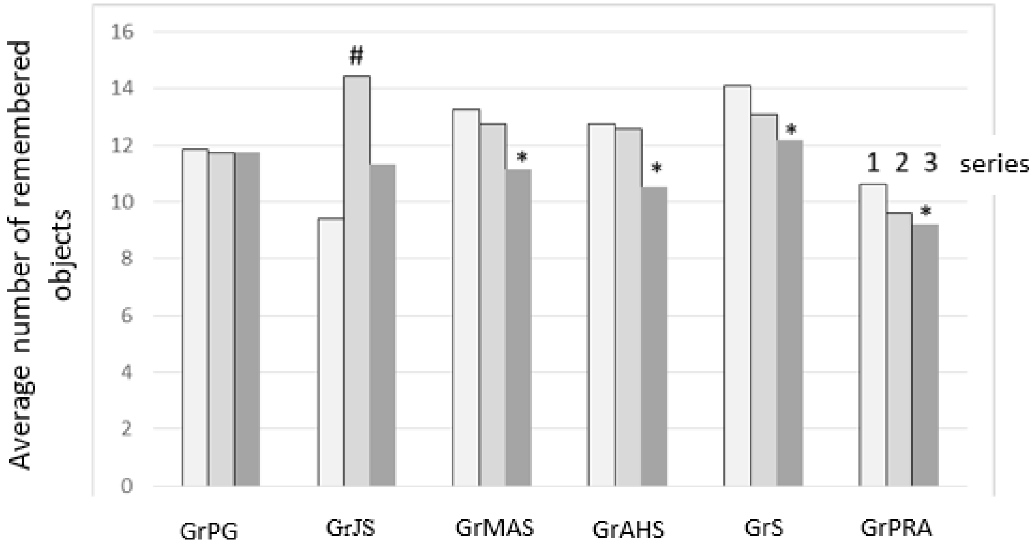
Note: *GrPG- preschoolers, GrJS - junior school students, GrMAS- middle school students, GrAHS - high school students, GrS - students, GrPRA – people of retirement age; * - p < 0.02 with Bonferroni correction for GrPRA compared to GrMAS, GrAHS, GrS.*

No significant effect was found for the ***GENDER*** factor.

The effect of ***age*** on the dynamics of the reproduction of memorised objects according to the detected interaction effect AGE x SERIES ($F_{10,\ 1094}$) = 1.81; $p < 0.05$; $\eta^2 = 0.02$) is shown in Figure 3. This effect is due to differences in the reproduction of objects presented in Series 1, with significantly greater performance compared to Series 3 for the four groups: GrMAS, GrAHS, GrS and *GrPRA*, but no such differences for preschoolers (GrPG) and a maximum reproduction value for younger pupils (*GrJS*) in series 2 compared to series 1 and 3.

Figure 3

Influence of age on the dynamics of memory trace reproduction in three series of visually presented stimuli



Note. *Group designations as in Figure 2 and Table 1; * - p < 0.05 in series 3 compared with series 1, # - p < 0.01 in series 2 compared with series 1 and 3.*

Age-specific proactive interference effects in short-term visual memory related to retrieval performance

In the next stage of the analysis, three groups were identified that differed in mean reproduction values according to the distribution of total memory scores: respectively, with low scores of 5.2 $\pm$ 0.5 (45 individuals) (GR0); medium 10.0 $\pm$ 0.2 (345 individuals) (GR1) and high 16.0 $\pm$ 0.2 (167 individuals) (GR2).

Table 2 presents the numerical composition of the three formed groups (GR0-GR2) and the corresponding mean values of memory indices for the six age groups. Significant differences in quantitative composition were found only when comparing students (GRS) and elderly (GRP) in GR0 with a greater representation of the number of elderly people with low memory indices ($p < 0.02$ according to Chi^2).

Table 2

Numerical composition and number of memorised objects (memory capacity) in groups differing in the efficiency of memory trace reproduction (GR0-GR2) as a function of age (GRPG-GrPRA)

Group	Indi-cator	GrPG	GrJS	GrMAS	GrASH	GrS	GrPRA
GR0	N (%)	6 (7)	8 (14)	4 (6)	1 (3)	10 (5)*	16 (13)*
	volume	17,0 ± 2,8	15,3 ± 2,4	13,0 ± 3,5	15,0 ± 6,9	17,4 ± 2,2	16,5 ± 1,7
GR1	N (%)	60 (67)	30 (54)	37 (58)	18 (49)	114 (60)	86 (71)
	volume	31,2 ± 0,9	28,5 ± 1,3	31,4 ± 1,1	29,6 ± 1,6	30,8 ± 0,7	28,4 ± 0,7
GR2	N (%)	23 (26)	18 (32)	23 (36)	18 (48)	67 (35)	19 (16)
	volume	47,4 ± 1,4	46,7 ± 1,6	47,3 ± 1,4	46,3 ± 1,6	51,9 ± 0,8	48,0 ± 1,6

Note. ** - p < 0.02 according to Chi criterion²*.

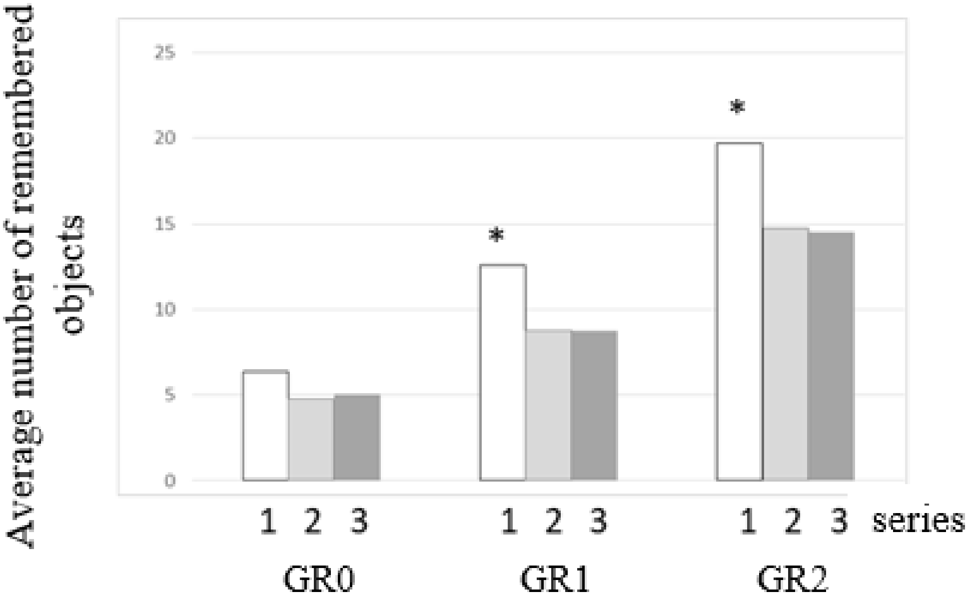
ANOVA with the factors GROUP (3), GENDER (2) and SERIA (3) revealed a trend for a GROUP x SERIA interaction effect ($F_{4, 1078} =$ 1.85; p < 0.12) due to no significant change in GR0 and a similar RIF effect in GR1 and GR2 (Figure 4).

The planned analysis of the dynamics of stimulus reproduction in three series of stimulus presentations revealed the general age-independent effects of the absence of significant changes in the group with low reproduction volume (GR0) and a pronounced manifestation of RIF in subjects with better memory capacity (GR1 and GR2) (p < 0.0001). Moreover, this effect was noted for the 2nd series of presentation and persisted in the 3rd series (Fig. 4).

A significant GENDER x SERIA interaction effect ($F_{2, 172} =$ 3.30, p = 0.039) was found in GR1 for preschoolers (GRPG) and junior school children (GRJS): RIF was characteristic of girls but absent in boys (Table 3).

Figure 4

Peculiarities of temporal dynamics of the reproduction index in three series of stimulus presentation for three formed groups differing in memorisation efficiency: GR0 - low, GR1 - medium, GR2 - high



***Note.* * - p <0.0001 when comparing the rates in series 1 with the other two series.**

Table 3

Peculiarities of temporal dynamics of remembering visually presented stimuli by boys and girls from groups of preschoolers and junior schoolchildren

Series	Playback	
	Boys (n=42)	Girls (n=48)
1	10,1 ± 0,8	13,4* ± 0,8
2	9,9 ± 0,8	8,8 ± 0,8
3	8,9 ± 0,8	8,5 ± 0,8

Note. ** - p <0,01.*

Discussion

We obtained data according to which the most pronounced decrease in reproduction in visual memory occurs in old age, and the peak of memorisation occurs at the age of twenty.

These results are consistent with the previously noted age-related dynamics of visual memory due to the development of mechanisms of executive control of information selection and binding of elements of visual images and their impairment in aging due to inhibition deficit in the visual system (Brockmole & Logie, 2013; Gazzaley et al., 2008). Despite lower scores compared to children and young adults, the RIF effect is present in the HGP, with greater expression of this effect in older adults accompanied by better executive control of attention (Razumnikova, 2019), and successful memory recall is ensured by reorganisation of neural networks involving temporal and dorsolateral prefrontal cortex (Bennett, Sekuler, McIntosh & Della-Maggiore, 2001). Consequently, it is the resource capacity of the executive system of behavioural control that underlies the retention of short-term visual memory in old age.

According to the results of the performed analysis of the dynamics of short-term visual memory performance, RIF is absent only in GR0 with the lowest memory performance (see Figure 4), in GR1 it is detected in younger girls (but not boys) and is maximally expressed in GR2 (with the best memory performance). Executive control functions are known to form earlier in girls than boys during childhood (Chaku & Hoyt, 2019; Vrantsidis, Wakschlag, Espy & Wiebe, 2022), although recent research suggests that the effect of individual variability is greater than gender in age development (Thanadkit, Sudjainark, Boonpleng & Kulsaravuth, 2021; Wierenga, Bos, van Rossenberg & Crone 2019).

Our findings support the link between RIF and established inhibitory functions in information selection (Friedman & Miyake, 2017), and that sustained RIF is characteristic of individuals with better memory (Aslan & Bauml, 2011). This interference effect is attributed to the inhibition of irrelevant information as a function of prefrontal cortex. Since the neuroanatomical model of inhibitory modulation of memory trace reproduction, includes 1) switching attention to other stimuli, 2) inhibition of individual memory representation and 3) generalised hippocampal inhibition and reactivation processes of reproduction (Depue, 2012), then in ontogeny each of these processes may acquire leading importance. In childhood it is attention switching, in young adulthood it is inhibition in formed engram neural networks, and in old age it is predominantly hippocampal. These age effects along with their individual variability of involvement in the mechanisms of reproduction determine the diversity of the dynamics of memory indices.

A stable process of proactive interference is formed only by age 10, as evidenced by the presence of the RIF effect generalised for all four older age groups (GrJS-GrPRA) (Figure 3), with no significant serial changes in reproduction in the GrPG and its pronounced dynamics in groups of schoolchildren (of different ages) with an increase in the number of memorised objects in the second series followed by a decrease in this indicator in the third series. In preschool age, apparently, memorisation strategies are very diverse, and the final result in the GrPG is represented by the summation of at least three effects: RIF strategy formed in one part of the children, whereas Retrieval-BasedLearning (RBL) may predominate in another part (Pastötter, Schicker, Niedernhuber & Bäuml, 2011; Roediger & Karpicke, 2006), and uncontrolled spontaneous memorisation in a third part.

A distinctive feature of GrJS is the dominance of the RBL effect during memory recall in series 2, which in the next stage of object memorisation already leads to the development of RIF. The RBL effect is useful for effective learning and intellectual development (Karpicke & Blunt, 2011; Pastötter & Bäuml, 2014). In this regard, its dominance in younger pupils seems to indicate a successful educational programme and the children's ability and motivation to acquire new knowledge.

Working memory, including visual memory, is a component of executive functions, the main task of which is to control the transition process from habitual behaviour to new behaviour (Nikolaeva, Vergunov, 2017). Consequently, therefore, we see an externally conditioned activation of executive functions related to achievement motivation at the initial stage of school education, which, apparently, is not so relevant in other age groups.

The features of working memory at preschool age reveal a biologically unfolding process due to the gradual formation of inhibitory control in immature prefrontal cortex (Nikolaeva, 2019). At the same time, preschool children have active learning, which is found in the absence of a sharp drop in reproduction from series to series. However, both the process of proactive interference and learning are far from a mature state. This is why children of this age easily learn new information and forget it with equal ease. Undoubtedly, this is an evolutionarily conditioned process, as the child is not yet able to sustainably identify relevant information (Nikolaeva, 2011).

Memory deterioration in old age is not only due to the biological aging process, but also due to a decrease in motivation to try different strategies, invent them and incorporate them into daily life (Razumnikova, 2015; Razumnikova, Nikolaeva, 2019). Studies of engaging the elderly for cognitive training and activation of cognitive resources indicate that only a small part of them is capable of mastering new activities (Razumnikova, Asanova, 2018). However, people in creative professions, such as conductors, actors, or those engaged in scientific work, are able to retain quite large amounts of information in memory because they are motivated to change strategies for effective professional activity. Consequently, an important recommendation for maintaining effective memory functioning in aging is learning strategies to assimilate new information, which is a natural process at a young age.

Conclusion

The effect of proactive interference (RIF) in remembering visually presented figurative information is poorly represented in preschoolers, develops with age, reaches maximum expression in twenty-year-old students and persists in retirement age, despite the noted weakening of memory in the elderly.

The RIF effect, regardless of age, accompanies the best reproduction performance and is absent in the group with weak memory. At average memory performance RIF is related not only to age but also to the gender of preschoolers and younger schoolchildren: at the age of 6-8 years RIF is characteristic of girls but not of boys. The best memory performance and maximum proactive interference are noted in twenty-year-old students.

Thus, the effect of proactive interference develops with age and favours better recall of a series of visually presented objects, with the peak of memory recall reaching at age 20 and its subsequent weakening at age sixty. The critical period for the development of this effect is age 6–8 years. The absence of age differences in the temporal dynamics of visual memory recall at both its low and high values can be attributed to a complex of factors not taken into account in the present study, for example, the combination of different memorisation strategies and the flexibility of their use depending on individual motivation to perform the task.

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Olga Mikhailovna Razumnikova developed of the research concept, organized the data collection, data analysis and interpretation, literature review, work with the text of the article.

Elena Ivanovna Nikolaeva organized the data collection, scientific advice, editing and work with the text of the article.

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Conflict of Interest Information

The authors have no conflicts of interest to declare.