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To cite this article: M. I Introzzi, M.F López Ramón, M. J García, E.V Zamora, M. Musso & M. Richard's (2024) Selective Attention (SA) and Perceptual Inhibition (PI) Throughout the Lifespan, Journal of Cognition and Development, 25:4, 529-548, DOI: [10.1080/15248372.2024.2325014](https://doi.org/10.1080/15248372.2024.2325014)

To link to this article: <https://doi.org/10.1080/15248372.2024.2325014>



Published online: 20 Mar 2024.



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Selective Attention (SA) and Perceptual Inhibition (PI) Throughout the Lifespan

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ABSTRACT

The aim of this study was to analyze the development of Perceptual Inhibition (PI) and Selective Visual Attention (SVA) across lifespan, identifying key moments of change in the direction of development. A total of 810 Argentinian participants, ranging from 6–80 years, were included. The results revealed that PI and SVA followed similar patterns, characterized by a linear function with three phases and two significant transition zones. The first phase spanned from childhood to early adolescence, showing a rapid and constant improvement in PI and SVA efficiency until 11 and 13 years. Subsequently, the next developmental phase is more extensive and lasts about 40 years. This phase is characterized by stability with a slight decline. In older adults another transition was identified, with a progressive decline until 80 years. It is important to note that the decline in older adults was much slower than the rapid improvement observed in childhood and adolescence, suggesting that the decline in older adults was not an inverse mirror image of their early development. PI showed a continuous improvement between the ages of 6 and 11, reaching a similar level of performance as young adults. On the other hand, SVA indexes showed a linear and progressive improvement from 6 years of age, but the first transition in the other direction was registered at 13 years of age. In summary, this study highlighted that both PI and SVA followed nonsymmetrical developmental patterns, with rapid early improvements in childhood and adolescence, and a slower decline in older adults.

Introduction

Selective visual attention (SVA) is a complex cognitive function that guides or directs our attention to objects or stimuli in the environment that interest us or are relevant to an ongoing task or activity (Parasuraman, 1998; Schmeichel & Baumeister, 2010). As with any complex function, multiple cognitive processes or mechanisms are involved, with inhibition being one of the most important (Diamond, 2013; Hasher & Zacks, 1988; Treisman & Sato, 1990). Generally speaking, inhibition refers to the ability to slow or stop predominant tendencies linked to emotion, thought, behavior and

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environmental stimuli that can interfere with the achievement of our objectives (Nigg, 2017). In other words, inhibition makes it possible to control the interference generated by stimuli from the environment, thoughts or motor behaviors, which are imposed with force, that is, that are dominant and that are inadequate for the achievement of our goals. However, inhibition and interference are not the same (Dempster, 1993; MacLeod, 2007; Zamora, Richard's, Canet Juric, Aydmune, & Introzzi, 2020). Interference is a phenomenon that involves cognitive competition between stimuli, ideas or motor responses and is associated with a decrease in performance of an activity (Harnishfeger, 1995; MacLeod, 2007) and inhibition refers to the mechanism that acts against the interference, with the objective of exercising control over it, neutralize or counteract it (Dempster, 1992; Hofmann, Schmeichel, & Baddeley, 2012). Consequently, the greater the interference, the greater the effort that must be made to counteract it (Neill, Valdes, & Terry, 1995). This allows us to understand the close alliance between selective attention and inhibition.

Current models coincide on two basic principles of life course development; the multidirectionality that implies that while some capacities or characteristics increase others may decrease or reduce and the multidimensionality that implies the presence of different rates of development in different dimensions (Baltes, 1997; Baltes, Lindenberger, & Staudinger, 1998). In this way, empirical evidence has allowed us to distinguish among a set of inhibitory processes that exhibit distinct and specific operational characteristics, with different developmental trajectories. This has led to the development of multidimensional or non-unitary models of inhibition, proposing the existence of three main types of inhibitory processes: Perceptual Inhibition, Cognitive Inhibition, and Response Inhibition (Friedman & Miyake, 2004; Gandolfi, Viterbori, Traverso, & Usai, 2014; Howard, Johnson, & Pascual-Leone, 2014). Although these processes share a common function – the restraint or reduction of interference effects – they also differ based on the type of interference they aim to control: interference arising from the environment (i.e., perceptual inhibition), interference originating from representations or thoughts (i.e., cognitive inhibition), and interference stemming from automatic or strongly showed responses (i.e., behavioral inhibition).

In light of current multidimensional models, one of the inhibitory processes more implicated in the functioning of Selective Visual Attention (SVA) is Perceptual Inhibition (PI; Diamond, 2013; Introzzi, Zamora, Aydmune, Richards, & López-Ramón, 2022). A fundamental PI's functional property is the interference control from external stimuli, such as visual information. In other words, its main function is to reduce or attenuate the interference effects caused by distracting stimuli groups (see Friedman & Miyake, 2004; Hasher, Lustig, & Zacks, 2007; Introzzi, Andrés, Canet-Juric, Stelzer, & Richard's, 2016). Therefore, PI is essential for SVA functioning; firstly, because it facilitates the highlighting of the salience of the target relative to the distractors, and secondly, because it facilitates attentional orienting toward ongoing activity goals (see experiment 4 in Treisman & Sato, 1990). The collaborative efforts of PI and SVA enhance information processing efficiency by prioritizing or facilitating relevant content's processing during visual stimulus handling (i.e., thereby avoiding system overload) As a result, the joint processing work of PI and SVA plays a crucial role throughout development and constitutes an indisputable contribution to emotional and cognitive self-regulation processing (Best, Miller, & Jones, 2009; Diamond, 2013; Introzzi et al., 2021; Mischel et al., 2011).

A well-known approach for measuring PI and SVA is to identify a target stimulus from varying numbers of distracting stimuli, as proposed by the visual search paradigm (Introzzi, Zamora, Aydmune, Canet Juric, & López, 2017; Treisman & Sato, 1990; Woods et al., 2013). In this sense, the conjunctive search task (see Treisman & Gelade, 1980) is a clear example of a visual search paradigm because it requires the identification of a target among a variable number of distracting stimuli. The uniqueness of this method lies in the fact that the target stimulus and the distractors share at least one visual characteristic or feature, and the individual must respond indicating the target's presence. According to Treisman and Sato (1990), in cases where visual characteristics are not easily discriminable (e.g., identifying a blue square among blue circles and red squares), inhibition intervenes by partially suppressing the activation of irrelevant characteristics (i.e., red and circle), which results in activation differences between the target and the distractors. When the distractors are numerous, attentional focus moves sequentially through the visual display, centering on small subgroups of stimuli. These differing modes of activation for each group are highly influential in facilitating the search process. In other words, if a target is present within a subgroup, it is quickly identified due to its high activation level, but if the target is not present, the activation level for the entire subgroup fails to be sufficient for a positive response, leading to the simultaneous dismissal of all the distractors in the subgroup (for a detailed explanation of the effect, see Treisman & Sato, 1990; Treisman, 2006).

Relevant findings have highlighted the selective engagement or impairment of PI and SVA in a heterogeneous group of neurodevelopmental disorders such as Attention Deficit Hyperactivity Disorder (ADHD; Bédard, Trampush, Newcorn, & Halperin, 2010; Garcia Pimenta, Gruhnert, Fuermaier, & Groen, 2024; Richard's, Introzzi, Zamora, & Vernucci, 2017), Autism Spectrum Disorders (Adams & Jarrold, 2012; Gorobets et al., 2023; Ko, Lin, & Lin, 2024), and reading problems (Chiappe, Siegel, & Hasher, 2000; Ouerchefani, Ouerchefani, Ben Rejeb, & Le Gall, 2024). Moreover, the role of these processes in fluid intelligence has been emphasized in both children (Stelzer & Urquijo, 2014), adults and older adults (Darowski, Helder, Zacks, Hasher, & Hambrick, 2008). Clearly, PI and SVA play an active role in several complex cognitive functions that are essential for proficient performance in daily life.

Throughout the lifespan, there is a rapid improvement, followed by an extensive period of stability, and a gradual decline. This pattern appears consistent with one of the fundamental principles of lifespan development postulated by theorists in Lifespan Psychology. According to this perspective, during ontogenetic development, biopsychosocial resources are competitively and somewhat systematically distributed among three basic evolutionary goals or functions: growth, maintenance, or regulation of losses (Baltes, 1997; Baltes, Lindenberger, & Staudinger, 1998). In terms of cognition, the primary developmental goal during childhood and adolescence is growth, in youth and middle age, it is maintenance, and in older adults, it shifts toward regulating losses. This developmental profile seems to align with the developmental trajectory observed for PI and SVA. In this regard, during the first phase of development (i.e., childhood to early adolescence) biopsychosocial resources seem to concentrate on achieving higher levels of functioning or adaptive capacity – the growth goal. In the second phase (i.e., youth and middle age) the primary efforts would be focused on preserving functioning levels attained in the previous phase (i.e., the maintenance goal). In the third phase (i.e., corresponding to older adults) actions

would be particularly geared toward organizing individual functioning at lower levels since maintenance is no longer feasible (i.e., the regulation of losses goal).

Therefore, the efficiency changes they undergo during different age ranges, have scientific relevance. However, many scientific studies have focused on specific age ranges such as childhood (Introzzi, Aydmune, Zamora, Vernucci, & Ledesma, 2019; Rebok et al., 1997), adolescence (Introzzi et al., 2021), or adulthood (Introzzi et al., 2020), or have covered broader developmental periods, including comparisons between two of them (e.g. such as childhood and adolescence, Introzzi, Andrés, Canet-Juric, Stelzer, & Richard's, 2016; Karns, Isbell, Giuliano, & Neville, 2015), or adults and older adults (Plude & Doussard-Roosevelt, 1989). In general, most studies point to both IP (Dupuis, Meier, & Cuneo, 2019; Madsen et al., 2020; and SVA (Introzzi, Aydmune, Zamora, Vernucci, & Ledesma, 2019; McAvinue et al., 2012) a development trajectory characterized by a rapid and sustained increase during childhood until the onset of adolescence. Traditionally, it is assumed that in adulthood there is an extensive period of stability that is maintained until old age (Craik & Bialystok, 2006; Hommel, Li, & Li, 2004) and that involves both IP and VAS, among other cognitive processes. However, recent studies have found that decline or decline begins earlier than assumed. For example, Ferguson, Brunsdon, and Bradford (2021) note that the decrease in inhibitory function begins as early as the 30s, while Ferreira et al. (2015) found that it begins in the 50s. However, despite these differences, there is still not enough evidence regarding the time when a decrease or decline in the functioning of different cognitive processes begins, more specifically regarding the executive functioning.

At the moment, there are also not enough studies that have jointly examined the changes shown by SVA and PI throughout the lifespan (e.g., from childhood to old age), likely due to a combination of factors such as: (a) the difficulty in obtaining an extensive sample that includes individuals from different age ranges (e.g., childhood, adolescence, older adults); (b) the need for a method suitable for evaluating children, adolescents, adults, and older adults (e.g., Best, Miller, & Jones, 2009; Hommel, Li, & Li, 2004); (c) the scarcity of tools providing differentiated indices or measures for the evaluation of SVA and PI.

So far, only two studies have recorded independent measures for evaluating SVA and PI. However, these studies only focused on one developmental age range, such as childhood (Introzzi, Aydmune, Zamora, Vernucci, & Ledesma, 2019) or adulthood (Introzzi et al., 2020). Therefore, this study aims to analyze the developmental trajectories of SVA and PI throughout a significant portion of lifespan (i.e., childhood, adolescence, adulthood, and older adults) using a conjunction search task that allows the evaluation of both processes and is simple enough to be applied to different age ranges. The results obtained will provide answers to a set of crucial questions related to the development of these processes, such as: (a) what are the main moments of change during the developmental trajectory of PI and SVA?; (b) do the moments of change in both cognitive processes coincide (i.e., meaning they have similar developmental trajectories throughout development?); (c) what shape do these trajectories take: quadratic, cubic, or linear?; (d) is there a linear relationship between age and childhood's changes?; (e) there is a linear relationship between older adults (i.e., regarding SVA and PI ?); (f) do the changes exhibit the same degree of acceleration?; and (g) is there symmetry between the increase in efficiency of both processes observed in childhood and the

decrease observed in older adults?. The present study represents an important contribution as it seeks to address these questions comprehensively.

Method

Participants

The sample was non-probabilistic (i.e., 810 subjects from 6 to 80 years of age). The children who participated in the study were students from first grade (i.e., 6 years of age) to sixth grade (i.e., 12 years of age), who attended two primary educational public schools in the city of Mar del Plata (Argentina). The adolescents evaluated (13 to 19 years of age) were attending high school (i.e., from two public institutions). In the case of children and adolescents, the following inclusion criteria were considered in the participant selection process: (a) students that had not repeated the current school year because of academic reasons; (b) with typical development (i.e., without diagnosed mental deficits and without a history of a developmental or learning disorder); and (c) with normal or corrected vision and hearing (i.e., conditions necessary to carry out the proposed activities). An additional checklist survey -*Child Behavior Checklist* (CBCL)- (argentinian version, Samaniego, 2008) was administered to parents in order to screen for any additional clinical aspects related with their physical and mental health.

For adults and older adults selection, the following inclusion criteria were considered: (a) adults who were not in psychiatric treatment; (b) no diagnosis of psychiatric and/or neurological impairment, focal or degenerative diseases; (c) higher level formal education of at least of seven years; (d) a score of more than 25/27 points (Argentine version of Butman et al., 2001) in the *Mini Mental State Examination* (MMSE), and (e) normal vision or corrected vision. The adults who formed part of this study were selected through two educational institutions in the city: 1) private and non-university higher education institutions, 2) public university institutions with bachelor's degree studies. Older adults were selected from non-governmental organizations and ongoing programs at the National University of Mar del Plata. A medium socio-occupational level was observed in all participants. In the case of children and adolescents, education levels for parents of the students in these two schools typically ranged from elementary school to a postgraduate degree, with a medium education level of a high school degree for both fathers and mothers, representative of low- to middle-socioeconomic status in Argentina. Regarding the socio-demographic characteristics of the adult group, 59% of the participants had a high level of education (tertiary or university), 36% reached secondary level, and the remaining 5% primary level. Of the total sample of older adults, 93% of the participants were retirees. Regarding the socio-occupational variable, 46% are professionals, 20% are qualified technicians/trades, 14% are employees/administrative workers, 11% are merchants, and 9% are housewives. The group of young adults registers a high level of education (75%), 20% have completed secondary school (8 to 12 years of formal education) and the remaining 5% have primary education (1 to 7 years of formal education). Regarding the occupational factor, 61% of them are professionals, 18% are qualified employees/administrative workers, 7% are technicians/trades, 7% are merchants, and the other 7% are housewives.

The sample was subdivided into age subgroups (See Data Analysis). To establish the age intervals, recommendations from studies on cognitive development throughout the lifespan were taken into account (e.g., Alterovitz & Mendelsohn, 2013; Hommel, Li, & Li, 2004). In general, these studies suggest working with small age intervals and multiple subgroups in older adults. Therefore, it was decided to divide the sample into one-year intervals during childhood and adolescence and five-year intervals during adulthood, starting from 20 years of age up to 80 years of age.

Data analysis

The data underwent analysis in several age ranges. In the first age range, an exploratory analysis of outliers corresponding to the two main performance indices – inhibitory control and selective attention – was conducted. Atypical cases were eliminated from each age group separately. Thus, 18 atypical cases were identified and removed following the criterion of 3.29 standard deviations beyond the mean (Tabachnick & Fidell, 2001), resulting in a sample of 792 subjects at this age range. This process aimed to neutralize the potential effect of variables that are difficult to experimentally control, such as participants affected by non-symptomatic and undiagnosed pathological processes, which could lead to “outlier” scores. In the second age range, the sample was divided into 26 age groups. To establish the age intervals, recommendations from studies on cognitive development throughout the lifespan were considered (e.g., Alterovitz & Mendelsohn, 2013; Hommel, Li, & Li, 2004). In general, these studies propose working with small age intervals and several subgroups in older adults. Therefore, one-year intervals were established during childhood and adolescence, and five-year intervals were used during adulthood, starting from 20 years of age up to 80 years of age. Then, in order to have an equal number of participants in each age group, 30 subjects were randomly selected for each group, except for the 6-year-old group, which ended up having 29 children. This resulted in a final sample of 779 participants.

Third, segmented linear functions (i.e., piecewise regression) were carried out in order to analyze the changes in cognitive function for different ranges of age, using STATGRAPHICS Centurion (Version 19.5.01). This form of regression is able to model non-linear relationships between variables and to capture different sets of changes without the assumption of symmetry. In addition, piecewise regression estimates the breakpoint between two linear segments and its confidence interval which provide a direct estimate of a transition zone (Fortenbaugh et al., 2015). Given the nature of the dependent variables (reaction times) we assumed the functions should be continuous. The first step was to graph the data and to visually estimate where the breakpoints appear to occur, using “robust lowess option.” Based on this visual examination (see Figure 2), a three-segments model with two breakpoints at 11 and 59 for PI was tested and fitted to the data. Following the same approach, a three-segments model with two breakpoints at 13 and 55 for SA was tested (see Figure 3). The breakpoints were the values of the independent variable (age mean of each group) where the slope of the linear functions changed significantly.

Procedure and ethical considerations

To carry out the study, the ethical considerations established for age were taken into account. The project was presented at the educational institution where informational meetings were held with the teaching staff, participants, and parents/guardians of the participants about the objectives and procedures of the study. In the case of children under 13 years of age, an information sheet was provided, and parents/guardians and children were invited to participate in the study, for which they had to sign an informed consent (IC). Likewise, the children had to consent to their participation, and could leave the study at any time if they required it. On the other hand, adolescents between 14 and 16 years of age must sign their IC, while their parents and/or guardians must consent to their participation. Those over 16 years of age only had to sign their IC. The activity was carried out in a classroom of the educational institution, specially designated for this purpose. In the case of adults, a CI was provided to carry out the study, which they had to sign and complete. In the same way, they could interrupt their participation at any time they wanted. The tests to be administered in this research, the treatment and the confidential use of data in accordance with the Declaration of Helsinki, and in line with the ethical principles and the code of conduct for psychologists established and reformulated by American Psychological Association (2017). The procedures outlined in the Argentinian National Law No. 25.326 (Protection of Personal Data, Law N° 25.326, 2000) on the protection of personal data regulated by Decree 1158/2001 were followed. Participation in the study was voluntary and subject to the informed consent of the participants and/or their parents and the consent of the underage participants.

The participants were evaluated individually in an interview that lasted between 10 to 15 minutes, regardless of the age of the participants. The experimental visual search task was administered on an HP LAPTOP- RJSENA2U computer with Windows 10 and a 15.6" screen. Additionally, in the case of adults (aged 20 to 80 years), the Mini-Mental State Examination (MMSE) was administered to evaluate cognitive functions and verify that participants surpassed the cutoff score established for inclusion in this study (according to the Argentine version by Butman et al., 2001).

Instruments

Conjunction Visual Search Task (CVT)

To assess Selective Visual Attention (SVA) and inhibitory control, the CVT from the Cognitive Self-Regulation Tasks was employed (Canet-Juric et al., 2018; Introzzi et al., 2020; Richard's, Introzzi, Zamora, & Vernucci, 2017). This task was based on the Conjunction Visual Search paradigm introduced by Treisman and Gelade (1980). In the CVT, participants were required to identify the presence or absence of a stimulus target, a blue square, amidst a variable array of distracting stimuli, including red squares and blue circles. The stimuli were constructed using double conjunctions, which combine two visual characteristics: shape and color. Furthermore, all distractors shared one of these visual characteristics with the target, ensuring interference effects and engaging selective attention. The task consisted of a practice block with 10 trials, followed by three experimental blocks, each containing 40 trials. Within each experimental block, there were 10 trials per condition

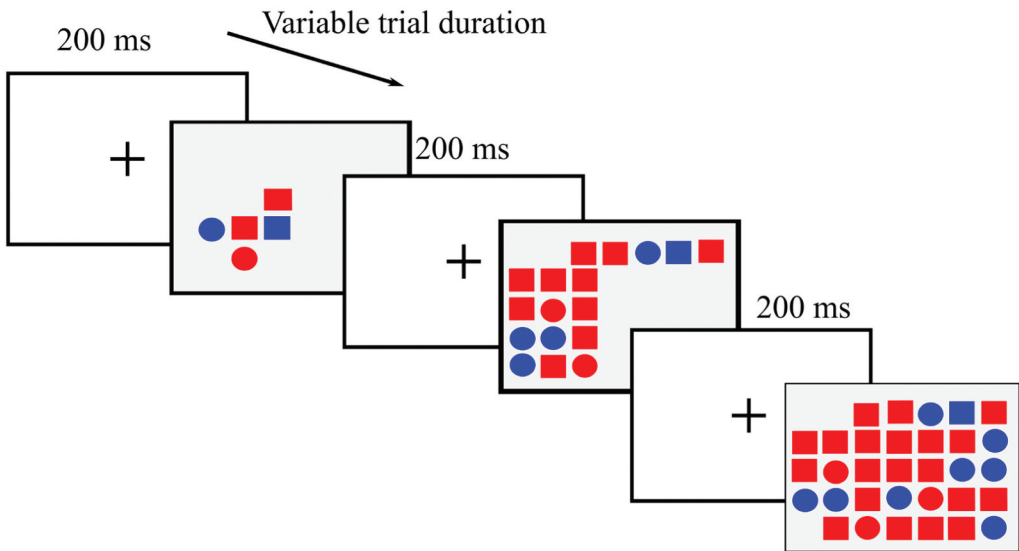


Figure 1. Trials of the conjunction visual search task with 4, 16, and 32 distractors.

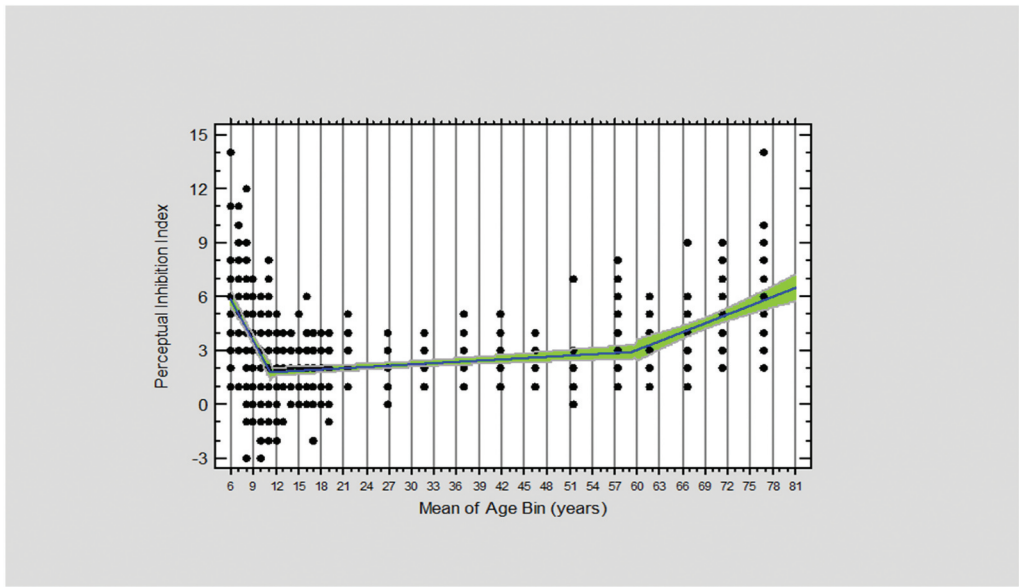


Figure 2. Changes in perceptual inhibition index for each of the age bins (years).
Note: Solid lines show the best-fitting model from the piecewise regression analysis. Green bar shows 95% confidence intervals.

of distractor numbers (i.e., 4, 8, 16, and 32 distractors). The 40 trials were randomly distributed in each block, with the target being present in 50% of the trials and absent in the rest. The task began with a fixation cross that was presented in the center of the screen for 200 ms (interstimulus interval, ISI). Then in a matrix not visible to the subject (i.e., of 7 × 6

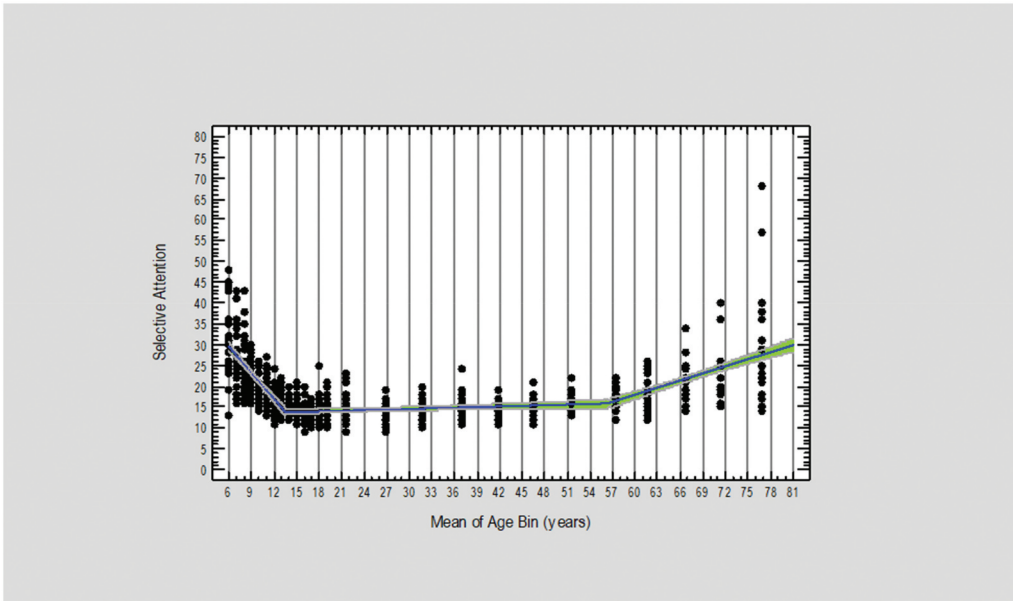


Figure 3. Changes in selective attention index for each of the age bins (years).

Note: Solid lines show the best-fitting model from the piecewise regression analysis. Green bar shows 95% confidence intervals.

cells, 9.5 cm wide by 8 cm high) stimuli were presented randomly distributed. They were kept on screen until the participant issued their response. Participants were required to respond promptly and accurately, indicating the presence or absence of the target by pressing the corresponding key (the “Z” key for a present target and the “M” key for an absent target). After each response, the subsequent trial appeared (Figure 1 illustrates the sequence of events in a given trial). Participants did not receive feedback on their response during the evaluation trials.

The CVT provided a set of indices for evaluating inhibitory control and SVA. All these indices were expressed in a measure called Inverse Efficiency (IE), which was recommended for use in tasks or tests where performance is analyzed through response speed and accuracy. As participants could prioritize either speed or accuracy when issuing their responses in each trial, it had been proposed that the most appropriate performance measure combined both aspects rather than analyzing each measure separately (e.g., Introzzi et al., 2020; Klein et al., 2004). The concept of IE was originally introduced by Townsend and Ashby (1983) and involves dividing the Response Time (RT) by the proportion of correct answers (accuracy). Since RTs were measured in milliseconds (ms) and were divided by proportions, the IE was also expressed in ms.

The Conjunction Visual Search Task yielded two different indexes for Selective Attention and Inhibitory Control assessment that are described below.

Selective Attention Performance Index

To evaluate selective attention, the Inverse Efficiency index -IE- was used in the condition of 32 distractors of the CVS Task. This measure was selected because it is the one that

requires the greatest demand for selective attention and the one that makes it possible to maximize intra-subject and inter-subject variability according to what has been reported in other studies carried out in different populations in this area with this task (Comesaña et al., 2019; Introzzi, Andrés, Canet-Juric, Stelzer, & Richard's, 2016; Richard's, Introzzi, Zamora, & Vernucci, 2017).

Inhibitory Control Index

To evaluate the inhibitory control mechanism, the differences in performance between conditions of 4 and 16 distractors of the Visual Search Task were selected. This measure is often used to assess the effect of interference and inhibitory control in different populations and conditions (see Mullane, Corkum, Klein, & McLaughlin, 2009). There are two main reasons why the difference between the conditions of 4 and 16 distractors was calculated: (a) comparing a condition where there is little interference effect and a minimal effort of the inhibitory control (4 distractors), with respect to a condition with interference and greater participation of inhibition (16 distractors); and (b) comparing two similar conditions (4–16 distractors) regarding the visual screening. That is, the time of visual search of the stimulus is sequential. Therefore, performance should be different between a condition with fewer stimuli and one with more stimuli. If the conditions of 4 and 8 distractors, or 4 and 32 distractors were compared, the differences in performance between them could be explained to a greater extent by visual screening than by the intervention of inhibitory control.

Results

Table 1 presents the descriptive statistics corresponding to the indices of Selective Attention and Perceptual Inhibition, distinguished by age group (see Table 1).

Subsequently, curve estimation was conducted, revealing significant effects for quadratic functions and cubic functions (see Table 2).

In performing the fit, the estimation process of the piecewise regression model to describe the relationship between PI and age, terminated successfully after 9 iterations, at which point the residual sum of squares appeared to approach a minimum. The model as fitted explained 33.42% of the variability in PI (adjusted R² = 32.99%). The equation of the fitted model is:

$$PI = 10.4604 - 0.76602 * \text{Mean Age} + 0.789501 * (\text{Mean Age} - 11.3034) * (\text{Mean Age} \geq 11.3034) + 0.140252 * (\text{Mean Age} - 59.3942) * (\text{Mean Age} \geq 59.3942)$$

Regarding the estimation process of the piecewise regression model to describe the relationship between SA and age, it finished successfully after 3 iterations. The model as fitted explained 55.69% of the variability in SA (adjusted R² = 55.41%). The equation of the fitted model is:

$$SA = 41.9417 - 2.08226 * \text{Mean Age} + 2.12461 * (\text{Mean Age} - 13.4723) * (\text{Mean Age} \geq 13.4723) + 0.532538 * (\text{Mean Age} - 56.3322) * (\text{Mean Age} \geq 56.3322)$$

As Figures 2 and 3 show, Perceptual Inhibition (PI) and Selective Attention (SA) have a similar pattern across the life span, with both being fit best by three-phase linear functions.

Both measures showed rapid decline of RT (an increase of the PI and SA abilities) between 6 and 11/13 years of age (respectively), then a period of relative stability until

Table 1. Descriptive statistics for each index across age groups.

Age group	Age (years)	SVA				PI				Females	Males
		Mean	SD	Min.	Max.	Mean	SD	Min.	Max.		
1	6	30,3	8,27	13	48	5,7	2,68	1	14	56,7% (n = 17)	43,3% (n = 13)
2	7	27,97	7,37	16	43	5,7	2,40	1	11	63,3% (n = 19)	36,7% (n = 11)
3	8	25,67	6,82	16	43	3,9	3,18	-3	12	50% (n = 15)	50% (n = 15)
4	9	22,33	3,85	16	30	3,5	2,00	-1	7	46,7% (n = 14)	53,3% (n = 16)
5	10	19,83	3,51	14	26	2	2,82	-3	6	60% (n = 18)	40% (n = 12)
6	11	18,9	3,43	13	27	2,77	2,18	-2	8	60% (n = 18)	40% (n = 12)
7	12	16	3,05	11	24	1,87	1,98	-2	5	60% (n = 18)	40% (n = 12)
8	13	16,7	2,97	12	22	2,07	1,14	-1	4	36,7% (n = 11)	63,3% (n = 19)
9	14	14,77	1,91	12	20	1,87	819	0	4	60% (n = 18)	40% (n = 12)
10	15	15,03	2,30	11	21	1,8	1,22	0	5	60% (n = 18)	40% (n = 12)
11	16	13,1	2,23	9	20	2	1,34	0	6	46,7% (n = 14)	53,3% (n = 16)
12	17	13,3	1,77	10	17	1,7	1,34	-2	4	63,3% (n = 19)	36,7% (n = 11)
13	18	13,97	2,86	10	25	2,37	964	0	4	90% (n = 27)	10% (n = 3)
14	19	14,3	2,97	10	21	1,67	1,24	-1	4	66,7% (n = 20)	33,3% (n = 10)
15	20-24	14,63	3,33	9	23	2,47	1,17	1	5	83,3% (n = 25)	16,7% (n = 5)
16	25-29	13,47	2,35	9	19	1,8	1,03	0	4	86,7% (n = 26)	13,3% (n = 4)
17	30-34	14,4	2,61	10	20	1,97	999	1	4	70% (n = 21)	30% (n = 9)
18	35-39	15,3	2,73	11	24	2,43	1,04	1	5	63,3% (n = 19)	36,7% (n = 11)
19	40-44	14,73	1,72	11	19	2,83	913	1	5	56,7% (n = 17)	43,3% (n = 13)
20	45-49	15,03	1,85	11	21	2,27	828	1	4	66,7% (n = 20)	33,3% (n = 10)
21	50-54	16,17	1,80	13	22	2,03	1,19	0	7	46,7% (n = 14)	53,3% (n = 16)
22	55-59	17	2,36	12	22	3,73	1,48	1	8	36,7% (n = 11)	63,3% (n = 19)
23	60-64	18,43	3,96	12	26	3,17	1,34	1	6	60% (n = 18)	40% (n = 12)
24	65-69	22,03	4,30	14	34	4,3	2,04	1	9	53,3% (n = 16)	46,7% (n = 14)
25	70-74	21,97	5,14	15	40	4,93	2,12	2	9	50% (n = 15)	50% (n = 15)
26	75-80	29,1	11,46	14	68	5,7	2,63	2	14	73,3% (n = 22)	26,7% (n = 8)

Table 2. Trends analysis of the relationship between age and dependent variables.

Variable	Linear (F)	Quadratic (F)	Cubic (F)
SVA	0.07	172.73***	154.10***
PI	5.08**	50.70***	47.35***

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

approximately 59/56 years of age respectively, and finally a decline in ability across older adults.

Specifically, the estimated break-points for PI were at 11.30 years of age (95% confidence interval, or CI = [10.60, 12]) and 59.39 (95% CI = [54.11, 64.68]). For SA, the estimated breakpoints were at 13.47 years of age (95% confidence interval, or CI = [12.91, 14.02]) and 56.33 (95% CI = [53.16, 59.50]).

Examining the slopes, or rate of change during each phase of the PI ability, we found that RT rapidly declined between 6 and 11 years of age, so PI improved during this phase ($-.77$ ms per year, 95% CI = $[-.91, -.61]$). This was followed by a period of relative stability with modest but significant increases in the RT between 12 and 59 years of age ($.04$ ms average per interval, 95% CI = $[.63, .94]$). At approximately 59 years, PI gradually declined ($.14$ ms every five years, 95% CI = $[.082, .297]$).

Similarly, for SA, the slope patterns highlighted a rapid performance improvement (decrease in RT) between 6 and 13 years of age (-2.08 per year, 95% CI = $[-2.32, -1.84]$).

Table 3. Parameter estimates for perceptual inhibition and selective attention in each three-segments model.

Parameter	Perceptual Inhibition	Selective Attention
Intercept	10.46 [9.14; 11.78]	41.94 [39.55; 44.33]
Slope 1	-.77 [-.92; -.61]	-2.08 [-2.32; -1.84]
First breakpoint	11.30 [10.60; 12.00]	13.47 [12.86; 14.08]
Slope 2	.04 [.02; .05]	.15 [-.10; .40]
Second breakpoint	59.39 [54.11; 64.68]	56.33 [53.16; 59.50]
Slope 3	.14 [.08; .20]	.53 [.42; .64]
R ²	33.42	55.69
Adjusted R ²	32.99	55.41
Mean Absolute Error	1.26	2.92

Note: Values in brackets are 95% confidence intervals.

This was followed by a period of stability between 14 and 56 years of age, with a slow but significant slowing in reaction time (.15 ms average per interval, 95% CI = [1.90, 2.34]). Performance then declined beyond age 56, with reaction time slowing at a rate of .53 ms every five years (95% CI = [.33, .52]).

For both measures, the estimated slopes during older adulthood were a fifth of those those observed during the childhood development period, which suggests that while participants showed a decline in task ability as they got older, the rate of decline observed from 59 (for PI)/ 56 (for SA) was not nearly as great as the rate of increase in task ability seen between 6 to 11/13 years of age respectively (see Table 3).

Discussion

The present study addresses several questions related to Perceptual Inhibition (PI) and Selective Visual Attention (SVA) development throughout the lifespan in an Argentinian sample. Our primary objective was to analyze the developmental trajectories of these processes and identify moments of significant developmental changes, that is, breakpoints or abrupt changes in the direction of a developmental pattern (e.g., increase, plateau, or declination). We examined whether these trajectories exhibit similar patterns of development and whether the rate or degree of acceleration of changes is consistent across different developmental periods such as childhood, adolescence, or older adults.

The results indicate that PI and SVA display similar developmental patterns across the lifespan. Both trajectories conform to a three-phase linear function with two significant transition zones interpreted as critical changes in the developmental patterns. The first phase encompasses childhood from 6 years of age and extends until the onset of adolescence. This period is characterized by a fast efficiency improvement in PI and SVA functioning, which continues steadily and progressively until 11 and 13 years of age, respectively. From this point, a much more extended second phase emerges, lasting approximately 40 years, during which no developmental changes (i.e., either in pattern or direction) are observed. As depicted in the graphs, phase 2 can be described as a prolonged period of stability with a subtle and hardly perceptible decline.

Subsequently, in late middle adulthood (i.e., when participants are 56/59 years of age), another developmental trajectory emerges, consisting of a gradual and progressive decline, that continues until 80 years of age and extends over a period of at least 20/25 years.

In summary, throughout the lifespan, there is a rapid improvement (i.e., in the first developmental phase), followed by an extensive period of stability (i.e., the second developmental phase described in the present work) and a gradual decline (i.e., the third developmental phase). This pattern appears consistent with one of the fundamental principles of lifespan development postulated by theorists in Lifespan Psychology. According to this perspective, during ontogenetic development, biopsychosocial resources are competitively and somewhat systematically distributed among three basic evolutionary goals or functions: growth, maintenance, or regulation of losses (Baltes, 1997; Baltes, Lindenberger, & Staudinger, 1998). In terms of cognition, the primary developmental goal during childhood and adolescence is growth, in youth and middle age, it is maintenance, and in older adults, it shifts toward regulating losses. This developmental profile seems to align with the developmental trajectory observed for PI and SVA. In this regard, during the first phase of development (i.e., childhood to early adolescence) biopsychosocial resources seem to concentrate on achieving higher levels of functioning or adaptive capacity – the growth goal. In the second phase (i.e., youth and middle age) the primary efforts would be focused on preserving functioning levels attained in the previous phase (i.e., the maintenance goal). In the third phase (i.e., corresponding to older adults) actions would be particularly geared toward organizing individual functioning at lower levels since maintenance is no longer feasible (i.e., the regulation of losses goal).

In general, regarding age-related physical changes, it has been widely accepted that there is symmetry during the lifespan development (Berger, 2009a; Schaie, Willis, & Caskie, 2004). Thus, youth and middle age are characterized by a clear strength and robustness that contrasts with the fragility or vulnerability inherent in childhood and older adults. Therefore, older adults are considered to have a reverse development (i.e., in relation to childhood and adolescence), as the rapid improvement and growth of the first two decades is equated with the rapid typical decline of older adults. This lifespan development idea is often represented by an inverted U-shaped curve and has also been used to describe the cognitive functions developmental trajectory (e.g., Craik & Bialystok, 2006). However, nowadays it is known that cognitive processes do not follow the same developmental pattern, and beyond the accepted differences between fluid and crystallized intelligence (Park, 2000), there is also evidence of distinct developmental patterns among executive control processes, and even among different inhibitory processes (Gandolfi, Viterbori, Traverso, & Usai, 2014; Vadaga, Blair, & Li, 2015). In relation to this issue, we wondered whether the developmental trajectory of PI and SVA exhibits an inverted U-shaped model compatible pattern, that is whether the decline observed in older adults presents as a symmetrical and reverse development to that of childhood and youth. The obtained results allow us to dismiss the symmetry or mirror image between the reported increase in childhood/youth and the decline in older adults. Both for PI and SVA, the rate of improvement during the first developmental phase is faster than one identified for the third phase decline. Specifically, for both measures, the estimated slopes during older adulthood were a fifth of those observed during the childhood development period, which suggests that while participants showed a decline in task ability as they got older, the rate of decline

observed from 59 (for PI)/56 (for SA) was not nearly as great as the rate of increase in task ability seen between 6 to 11/13 years of age, respectively.

Beyond the similarities between the trajectories of PI and SVA throughout the lifespan, there are also some differences and peculiarities. Regarding Perceptual Inhibition (PI), the present work showed a continuous and sustained improvement from 6 to 11 years of age. Thus, at 11 years of age (i.e., during puberty or the beginning of adolescence) the performance level of young adults is achieved, which, as mentioned earlier, remains relatively stable until 59 years of age. Despite the sample used was homogeneous in terms of the region of origin and socio-economic level, this trajectory is consistent with findings reported in most studies on inhibition development (Curley et al., 2018; Dupuis, Meier, & Cuneo, 2019; Madsen et al., 2020; Williams, Ponsse, Schachar, Logan, & Tannock, 1999). However, it is worth noting that all these studies focused on the development of response inhibition, whereas here, we explored changes related to PI, i.e., the ability to suppress or control interference generated by distracting stimuli present in the environment. According to our results and in the light of current inhibition models (see Vadaga, Blair, & Li, 2015), both developmental trajectories are characterized by rapid improvement, at least in childhood and adolescence, and reach their maximum efficiency at the age of 11–12 years. During adolescence and until 59 years of age – the second developmental phase – progress slows down, and relative stability with minimal decline emerges.

In general, it has been assumed that there are no cognitive changes in middle adulthood, which is why most developmental studies compare performance between young adults – aged 20 to 30 years – and older adults – over 60 – leaving out an entire developmental age range that includes people between 40 and 60 years of age. However, in recent years, it has been reported that the decline in inhibitory functioning may start much earlier than in older adults, as early as the 50s (Ferreira et al., 2015) or even in the 30s (Ferguson, Brunsdon, & Bradford, 2021). Beyond the lack of agreement on the onset of decline, the evidence obtained so far regarding inhibitory development in adulthood pertains to changes in behavioral inhibition. In this regard, our data suggest that PI follows a different developmental pattern, as a progressive decline in efficiency is only identified at 59 years of age. This constitutes an interesting contribution of this study, as it explores the development of an inhibitory type for which there is not enough empirical evidence, and it analyzes the entire adulthood age range without omitting any age range, considering intervals of 5 years from the age of 20. This has allowed for the more precise detection of transition zones where changes in the developmental trajectory occur.

Finally, the speed of decline in later adulthood cannot be interpreted as the developmental inverse of childhood, as the decline is 5 times slower than the increase observed in childhood. Thus, although the development of PI throughout the lifespan adheres to an inverted U-shaped model, where an increase is followed by a plateau and subsequent decline, the increase and decline do not manifest as mirror-symmetrical patterns or trajectories, as assumed in classic literature on inhibition development (e.g., Belmont, 1996; Dempster, 1992).

The development of SVA follows a trajectory similar to that of PI. Here too, a rapid, linear, and progressive increase is observed from 6 years of age. Regarding the SVA, the first transition zone where a change in direction is registered, appears two years later than the PI, at 13 years of age. These results differ from those reported by other studies (McAvinue et al., 2012), which show that SVA continues to improve beyond 13 years of age and that adult-

level performance is achieved between 15 and 17 years of age. On the other hand, several authors argue that PI -together with the Activation- constitutes the two main processes of SVA (e.g., Hasher, Lustig, & Zacks, 2007; Introzzi et al., 2021; Treisman & Sato, 1990). Despite limited evidence available on the topic, there are data showing a close relationship between inhibitory functioning and the ability to focus attention on certain objects or locations (Desimone & Duncan, 1995; Treisman & Gelade, 1980) in both children (Introzzi, Aydmune, Zamora, Vernucci, & Ledesma, 2019) and adults (Hommel, Li, & Li, 2004). The data obtained are consistent with the models cited regarding the nature of SVA understood as a complex cognitive function, composed of at least two main processes (See Treisman and Sato, 1990). In this way, PI shows an earlier development (11 years) than that of SVA (13 years). Overall, it is widely agreed that during childhood, SVA shows a progressive and linear improvement that continues even beyond adolescence (Donnelly et al., 2007; Merrill & Lookadoo, 2004). In other words, during adolescence, SVA continues to refine and increase in efficiency. However, our data indicate that SVA reaches its peak of development earlier, at 13 years of age, during early adolescence. Another noteworthy aspect is that the consistent increase in performance from 6 years of age to the onset of adolescence is three times greater in SVA than in PI. Then, starting from 13 years of age, a transition zone is identified where the growth slows down, and the maintenance phase begins, lasting at least until 56 years of age, characterized by minimal decline. From 56 years of age, another substantial change in the trajectory occurs, consisting of a progressive and linear decline that continues until at least 80 years of age. However, the speed or rate of this decline is almost four times slower compared to the rapid improvement – the first developmental phase – identified between 6 and 13 years of age. Hence, just like for PI, although the described trajectory aligns with the model of an inverted U – increase, maintenance, and decrease – the changes during old age should not be interpreted as the reverse of the development seen in childhood and early adolescence. On the other hand, it is worth noting that while in this study the developmental trajectory of SVA is compatible with an inverted U-shaped model, others have found a different pattern (McAvinue et al., 2012) characterized by a rapid increase peaking in adolescence, followed by a progressive and linear decline starting in the twenties and continuing into old age. This pattern differs from that found by the same authors for sustained attention, which follows an inverted U-shaped trajectory with a clear maintenance period in early and middle adulthood, followed by a decline in older adults.

The present study aimed to investigate the developmental trajectories of Perceptual Inhibition (PI) and Selective Visual Attention (SVA) across the lifespan. Our primary objective was to identify significant developmental turning points or abrupt changes in the direction of the developmental pattern (e.g., progress, stability, or decline). We explored whether these trajectories exhibited similar developmental patterns and if the pace or rate of change was comparable across different age periods, such as childhood, adolescence, and late adulthood.

Our findings revealed that both PI and SVA displayed similar developmental trajectories throughout the lifespan. Both abilities followed a three-phase linear pattern with two critical transition zones indicating significant changes in the developmental direction. The first phase encompassed childhood, from 6 years of age to the onset of adolescence, characterized by a rapid and steady improvement in PI and SVA efficiency until approximately 11 and 13 years of age, respectively. Subsequently, the second phase, which extended over

approximately 40 years from early adolescence to mid-adulthood (up to 56/59 years of age), demonstrated relative stability with a minimal decline.

The most intriguing finding emerged during the third phase, corresponding to late adulthood. While in PI, the decline was evident from 59 years of age onwards, in SVA, the decline was apparent from 56 years of age, preceding the decline in PI. This suggests that the age-related decline in SVA may be influenced by other cognitive processes, such as processing speed or cognitive flexibility, in addition to inhibitory mechanisms. These results deviate from traditional symmetric U-shaped models associated with cognitive development.

Furthermore, the magnitude of improvement observed in SVA from childhood to early adolescence was three times greater than that seen in PI over the same period. This supports the idea that SVA matures earlier than PI. However, It is noteworthy that the rate of decline observed in both abilities during late adulthood is substantially slower than the rapid improvement observed in childhood and early adolescence. This implies that the decline in late adulthood should not be perceived as a mirror image of development in early life.

This is probably explained by the relative influence of biology and culture during the development of the life cycle. According to Baltes (1997), biology and culture influence development, but the balance between these influences changes. In this sense, biological abilities weaken over the years, but the cultural foundations such as education, the relationships they cultivate and the technological environment of older people compensate for this deterioration by promoting the ability to adapt and cope with the problems of daily life. Therefore, there is also no mirror image between development in childhood and old age.

While these data support previous studies on vital trajectories on SVA and PI it is important to note that the entire sample with which we worked belongs to a particular region of Argentina, so generalization of these findings should be taken with caution. The present study focused on age-only differences. Therefore, among the limitations of the work are the lack of control of covariables such as income level, gender, and educational level of parents, which would give the possibility to generate adjusted explanatory models that would allow controlling cohort effects.

Findings from the present study contribute to a comprehensive and qualified understanding of the developmental trajectories of PI and SVA throughout the lifespan. The non-symmetric developmental patterns underscore the need to consider age-specific interventions and cognitive training strategies for optimal cognitive functioning across different areas of life. Thus, at different developmental stages, these cognitive functions would be more sensitive to interventions such as cognitive training or stimulation.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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