

## Article

# Elements of Biophilic Design Increase Visual Attention in Preschoolers

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**Abstract:** Biophilic design increases attention among adults, but little is known about the influence of biophilic design on attention in childhood. We assessed visual attention in 4–5-year-old children as a function of high and low degrees of biophilic design. In the high-biophilic-design condition, the children saw four plants, which were placed on their desks. In the low-biophilic-design condition, the children saw no plants on their desks. The children viewed a series of abstract images on a computer screen while their visual attention was measured with an eye tracker. We found that the durations of the children's first fixations were significantly higher in the high-biophilic-design compared to those in the low-biophilic-design. This study demonstrates the potential of biophilic design to increase visual attention in indoor environments. The implications of this finding for architecture and building design are discussed.

**Keywords:** biophilia; biophilic design; eye tracking; preschool children; school environment; visual attention



**Citation:** Fadda, R.; Congiu, S.; Roeyers, H.; Skoler, T. Elements of Biophilic Design Increase Visual Attention in Preschoolers. *Buildings* **2023**, *13*, 1160. <https://doi.org/10.3390/buildings13051160>

Academic Editors: Cinzia Buratti, Antonio Caggiano and Bo Hong

Received: 31 January 2023

Revised: 10 March 2023

Accepted: 20 April 2023

Published: 27 April 2023



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## 1. Introduction

Built environments have the power to influence health, wellness, and learning [1]. Buildings are generally separated from nature [2]. This increases the need to incorporate various biophilic features into the design of indoor environments.

Biophilia is the innate need to affiliate with nature (Wilson, 1984). Biophilic design strategies need to be implemented with consideration for those using the space. It also needs to consider the building's location and function [3,4]. For example, the procedures used to integrate biophilic design will be different for a living room, an office, a hospital, and a classroom. There have been many research studies on the possible benefits of biophilic design in the promotion of well-being in urban settings and workplaces [5]. One goal of biophilic design is to enrich indoor environments with natural elements or to bring natural elements from the outside, such as air and greenery, inside. As research shows, this improves well-being, happiness, and productivity at work [6,7].

Introducing nature indoors is a complex process that includes various dimensions [8]. To assist designers and urban planners, Kellert and Wilson [9] identified six biophilic design elements that can be incorporated into a given space: (1) environmental features, such as water, fire, and/or indoor plants; (2) natural shapes and forms; (3) natural patterns and processes; (4) light and space; (5) place-based relationships; and (6) human–nature relationships. The category “environmental features” includes elements that are well-recognized as natural characteristics in interior environments, such as living plants. Plants are important elements of biophilia [10]. Following up on Kellert's work, McGee and Marshall-Baker developed the Biophilic Interior Design Matrix (BID-M, 2012) to aid designers and other specialists in quantifying biophilic features in interior spaces. The matrix was created as a tool to identify biophilic features and to assess the presence and absence of these features in built environments. McGee and Marshall-Baker (2015) [11] first tested the BID-M to

assess biophilic-interior-design quality within hospital playrooms. Marte et al. (2020) [12] followed up on this research by assessing biophilic design in children's playrooms in New York City. The ability to reliably measure biophilic design is critical. Another issue is which elements of biophilic design influence behavior and wellness, and the ways in which the amounts of these elements matter.

Biophilic design is based on the Attention Restoration Theory (ART) [13] (Kaplan and Kaplan, 1989). The ART suggests that nature has a restorative effect on our attentional capacity. Built environments have distracting and cognitively taxing stimuli that require constant direct attention. This results in mental fatigue. Nature contains intriguing stimuli that require our unexacting attention. Direct, indirect, or representational exposure to natural environments activates bottom-up involuntary attention. This allows top-down directed attention abilities to replenish. Classically built environments require constant voluntary top-down attention [14]. Top-down attention is the voluntary allocation of attention to specific features, objects, or regions in space [15].

There are many gaps in the literature on biophilic design. One gap is in the identification of the aspects of biophilic design that affect human behavior and wellness. Another gap is in the determination of how sensitivity to biophilic design may develop in the early years. The majority of the research on biophilic design has been conducted with adults.

Berman et al. [16] demonstrated the restorative effect of biophilic conditions by exposing adults to natural stimuli during a walk in nature. Berto (2005) [17] also demonstrated the restorative effect of nature by showing adults photographs portraying natural scenes.

The placement of natural elements such as plants indoors exerts a restorative effect on well-being and cognitive performance among adults [14]. We are aware of two studies that investigated the beneficial effects of indoor plants on adults' cognitive performances. Raanaas et al. [18] found that the presence of plants in an office space improves cognitive performance and attention capacity in adults. Adults were tested in two conditions: one condition with four indoor plants and another condition without plants. The adults' attention improved in the condition with plants. Lipscomb and Rollings [19] found that adding plants to a workplace setting increased memory-task performance among adults.

As mentioned above, there are few studies on the influence of biophilic design in early childhood or infancy. We do know that the quality of indoor physical spaces directly affects early attention. For example, during infancy, having too many toys affects attention. Infants with fewer toys at home have increased sustained attention. In addition, heavily decorated classrooms disrupt children's attention and negatively affect learning [20] among elementary school children. As suggested by the Goldilocks effect, infants prefer visual sequences that are neither too simple nor too complex [21]. Little research has been conducted to assess how biophilic design may affect early attention. This is important for several reasons. Western children spend most of their day indoors. Children typically learn indoors, whether in homes, schools, or daycare facilities. Indoor environments are full of distracting and cognitively demanding stimuli that require the constant inhibition of direct attention [2]. This results in mental fatigue.

There are a handful of studies on the influence of nature on children. Dadvand et al. [22] studied the effects of lifelong residential exposure to green environments among young children. They examined visual attention in a sample of 1119 children, and how it related to the greenness of the everyday residential environments in which the children had grown up. The four-to-five-year-old children with higher lifelong exposure to residential greenness had fewer errors during testing. They also had lower response times, which were consistent with better attention. This suggests that exposure to residential greenness influences attention.

Faber Taylor and Kuo [23] found that 7–12-year-old children with attention-deficit disorder who walk in nature have better attention than those who walk in urban environments. The children were guided on a walk in a city park and in two well-kept urban settings. The children's concentration was measured using a Digit Span Backward task after each guided walk. The children concentrated significantly better after the walk in the

park compared to the downtown walk and the neighborhood walk. These results showed that a twenty-minute exposure to a park setting improved attention in children diagnosed with attention-deficit disorder.

In another study, Amicone et al. [24] demonstrated the positive effect of recess time spent in a natural environment compared to a built environment. The researchers evaluated ten-year-old children's attentional restoration by measuring sustained and selective attention, working memory, and impulse control. This experiment was conducted before and after morning-recess time, in two conditions. The children played a competitive team game similar to basketball. One group played in a natural environment. The other group played in a built environment. The results indicated that the children increased their sustained and selective attention, concentration, and perceived restorativeness in the natural-environment condition.

Berto et al. [25] examined the restorative effect of nature on 9–11-year-olds. The children were assessed in three conditions: (1) in the classroom after the practice of mindful silence; (2) in the school playground after the school break; (3) in an alpine wood after a walk. The children in the mindful-silence condition sat in a classroom and practiced a 90-min mindful-silence session. They were instructed to sit on the floor in silence and become aware of their breathing. In the play-time condition, the children played in a school-playground area for 90 min. The playground featured green areas and small trees. In the alpine wood condition, the children walked for 90 min with a teacher in an alpine wood, a natural environment with conifers. The researchers used the Perceived Restorativeness Scale to evaluate the restorative effects of each environment. The children were given a series of statements, such as: "In this place, I can relax mentally and physically." They were instructed to make judgments. The children found the alpine wood condition to be the most restorative. This aligned with Kaplan's Attention Restoration Theory. However, the children also found the mindful-silence condition in the classroom to be more restorative than the playground condition. This indicates that the type of activity performed influences perceived restoration.

All these studies indicated that spending time outdoors in natural environments exerts a positive effect on concentration and attention in children. Even after a short exposure to an outdoor natural environment, positive effects on attention and concentration are observed.

The indoor environments designed for children often lack most of the elements of biophilic design [12]. One way of overcoming this lack is to introduce nature into interior-building settings designed for children. Gunn et al. [26] conducted a meta-analysis of the literature on biophilic design. They investigated the potential benefits of implementing interior green walls in schools to promote the well-being of primary-school children. They found that the view of indoor plants and green walls has a positive impact on children's stress, anxiety, mood, and well-being.

Several experimental studies indicate that biophilic environments have positive effects on infants and young children.

For example, van den Berg et al. [27] measured attention and classroom evaluation before and 2 and 4 months after the introduction of green walls made of living plants in the classrooms of two elementary schools. They showed that 7–10-year-old children in classrooms with green walls scored better on a selective attention test compared to children in classrooms with no green walls. Moreover, self-report measures showed that after 4 months, the classroom with green walls was more attractive to the children than the classroom without green walls.

Van den Bogerd et al. [27] demonstrated the beneficial effects of indoor nature (i.e., potted plants and green walls) on attention in secondary-school students. The sample included 213 students, with a mean age of 14.53 years. The students were evaluated after one lecture in three environments: a classical classroom, a classroom with potted plants, and a classroom with flowers in vases. Self-reported attention was measured using three items based on items of sub-scales on standardized tests. The results indicated greater

attention in the students attending the lectures in the classrooms with potted plants and the classroom with flowers than in the classrooms without natural elements.

Lindemann-Matthies et al. [28] investigated the possible beneficial effects of windows and indoor plants on attention and concentration in school children. The study included 634 children, aged between 8 and 11 years. The researchers evaluated subjective well-being, short-term attention, short-term concentration, and connectedness to nature. The results indicated that the students focused more in the classrooms with more natural window views. The number of plants in each classroom was not significantly associated with the tested variables. However, the researchers did not control for the number and exposure of plants, nor their size, appearance, or scent.

Barbiero et al. [29] compared a conventional learning environment with two nature-based environments with biophilic designs. The biophilic environments included colors, biomorphic forms, diffuse light, visual connections to nature, and other properties of natural outdoor environments. A group of 20 children aged between 6 and 11 years was evaluated in a conventional learning environment in the first year and in biophilically designed environments in the next two years. The researchers evaluated the children's perception of restoration by using the Perceived Restorativeness Scale—Children, based on the ART [30]. The researchers also evaluated the children's attention with the Italian version of the Continuous Performance Test (CPT; Cornoldi et al., 1996) [31]. The results indicated that the learning environments with biophilic designs enhanced pupils' sense of restoration and attentional performance.

Determan et al. [32] examined the possible beneficial effects of biophilic design on stress and learning outcomes in mathematics for middle-school students. The study involved a sample of 857 students in grades 6 to 12. The data were collected over a period of seven months from students attending a biophilic classroom and a traditional classroom. The biophilic classroom included views of nature, dynamic and diffuse daylight, and biomorphic patterns. The results indicated that the average mathematics-test scores were three times higher for the students attending the biophilic classroom compared with the results obtained by the students in the classical classroom.

All these studies indicated that plants and green walls in schools and classrooms increase concentration, attention, learning, and connection with nature in younger and older students.

However, all these studies investigated children's top-down voluntary attention with cognitive tasks after exposure to elements of biophilic design. To the best of our knowledge, so far, no studies have investigated both top-down voluntary and bottom-up involuntary attention in children after exposure to elements of biophilic design at school.

The goal of this study was to assess the influence of biophilic design on children's visual attention from both top-down and bottom-up perspectives.

We compared children in two conditions: (a) a high-biophilic-design condition, which included indoor plants; and (b) a low biophilic design condition, with no indoor plants. We predicted that the high-biophilic-design would increase the children's visual attention. We measured visual attention with an eye tracker during the scene viewing. Eye-tracking data can provide precise information on the duration of visual attention in different dimensions, including both top-down and bottom-up attention processing [33]. This may reveal new insights into children's visual attention as a function of exposure to elements of biophilic design. We showed four abstract paintings to the children. Two of the paintings had geometrical and non-figurative shapes and two had simplified social contents. We selected these paintings because they can optimize visual attention in infants and adults, especially when complexity is reduced [34]. This series of stimuli was intended to activate a combination of top-down and bottom-up visual processes. Top-down mechanisms are crucial in perceiving social stimuli [35]. Bottom-up processing is central in perceiving image-dependent features of stimuli, such as intensity and color [36].

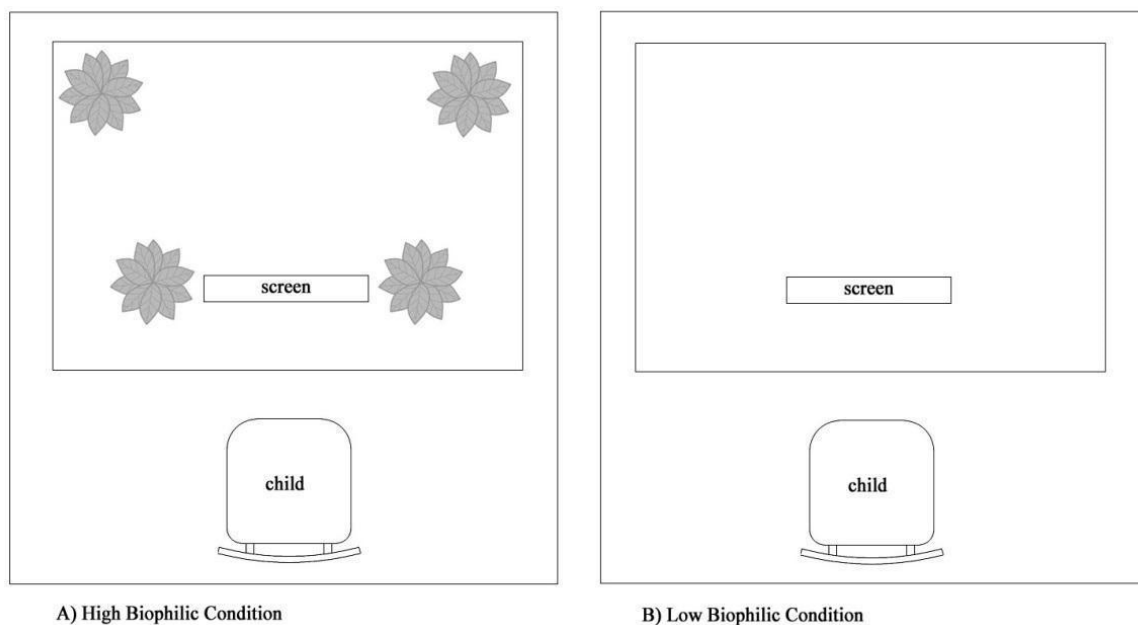
## 2. Materials and Methods

### 2.1. Participants

We enrolled 36 children in this study. One child was excluded because he had a history of cognitive delay. Two children were not tested because they were absent during the appointments. Four children were excluded because they did not complete the task. The final sample included 29 children. There were 15 children in the high-biophilic-design condition (6 females; 8 males). Their ages ranged between 57 and 70 months (mean age = 61.8; SD = 3.7834). There were 14 children in the low-biophilic-design condition (5 females; 9 males). Their ages ranged between 57 and 70 months (mean age = 63.00; SD = 3.616).

### 2.2. Setting

As shown in Figure 1, children sat at a viewing distance of 65 cm away from a 17-inch wide TFT eye-tracking monitor (Tobii T60) with a resolution of 1280 × 960 pixels. In the high-biophilic-design condition, four plants were placed on the desk, two approximately 10 cm from the computer screen on the left and on the right side, and two approximately 60 cm away from the computer screen. All the plants were visible from the child's point of view.

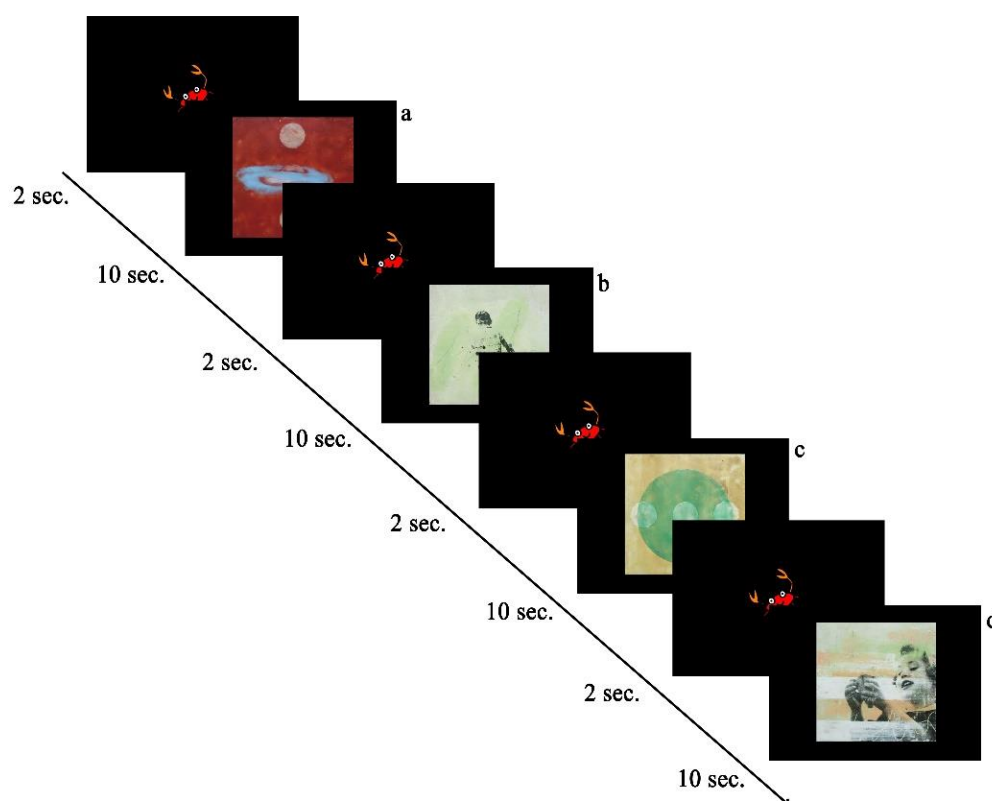


**Figure 1.** High-biophilic-design setup (A) with subject 65 cm away from monitor and plants out of reach. The low-biophilic-design setup (B) was the same, except for the presence of the plants.

### 2.3. Procedure

During the beginning of the session, the children met the research assistant. Children were tested individually at school, in a room dedicated to our study. This allowed us to control the intensity of the lights, the sounds, and the temperature, which was regulated with the heating set at 20 °C. Children were randomly assigned to either the high-biophilic-design condition or the low-biophilic-design condition through a procedure of matching for gender and age. In the high-biophilic-design condition, children were surrounded by 4 indoor plants, which were positioned close to the computer screen before each participant entered the room. The plants were not included in the low-biophilic-design condition. Children were instructed to sit in a chair facing a 17-inch wide monitor on a desk, at a viewing distance of approximately 65 cm. The research assistant told each child that he or she would see some images appearing on the monitor and invited the child to sit still. Next, the experimenter proceeded to the calibration (instruction for the calibration: “You will

see 5 red moving circles on the monitor, let's count them together!"). After each successful calibration, the experimenter proceeded to the testing phase (instruction: "Now you will see some images."). The experimenter operated the eye tracker from a laptop computer non-visible to the children. Children saw 4 stimuli, with each stimulus displaying for 10 s. The stimuli were a series of 4 paintings. Children viewed a central attractor, on a black background, for an interstimulus interval of 2 s. The sequence of stimuli was fixed for all participants and lasted 48 s (Figure 2).



**Figure 2.** The experimental paradigm included 4 paintings: (a) two pink circles and a blue ellipse on a red background; (b) a boy; (c) three little white circles and a big green circle on a yellow background; (d) a girl. We presented the stimuli in a fixed order. We displayed each stimulus for 10 s. Participants viewed a central attractor, a small drawn character swinging at the center of the screen accompanied by a sound, on a black background, for an interstimulus interval of 2 s.

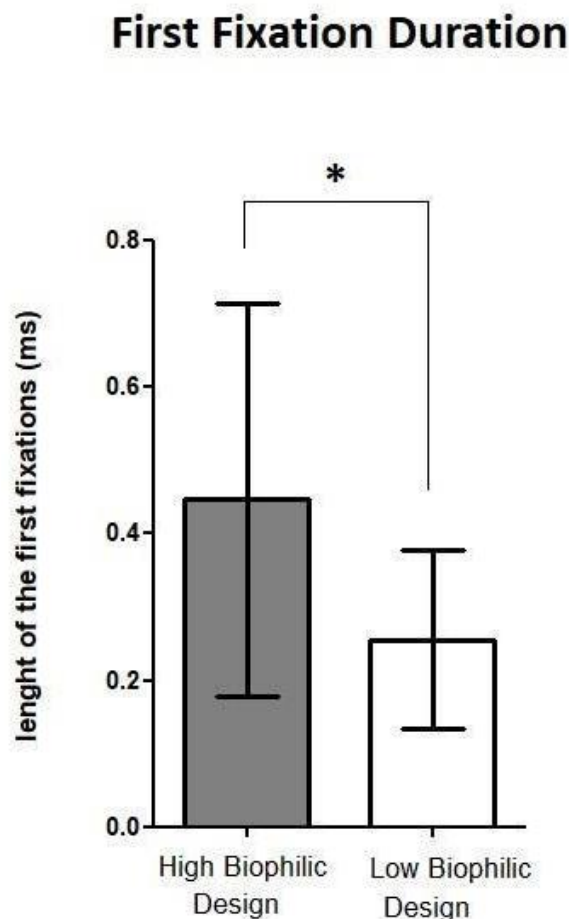
The study was approved by the Institutional Review Board committee of the Department of Pedagogy, Psychology, Philosophy of the University of Cagliari (Italy). Informed written consent was obtained by the parents of each participant.

#### 2.4. Coding

We set up an area of interest equivalent to the whole area of the stimulus images. We recorded a series of measures of participants' visual fixations. Visual fixations are defined as the point of focus between any two saccades, during which the eyes are relatively stationary and virtually all visual input occurs. We measured the time to first fixation, the first-fixation duration, the fixation count, and the total looking time. The time to first fixation was the latency, or how long it took children to fixate for the first time in the area of interest. The first-fixation duration was the length of the first fixation to the area of interest. The fixation count was the number of fixations to the area of interest. The total looking time was the sum of all the time during which participants looked at an area of interest. The looking time was defined as an uninterrupted sequence of fixations within an area of interest.

### 3. Results

We ran a series of t-test comparisons, which revealed no gender effects in the measures that we considered. Therefore, we did not consider gender effects further. As shown in Figure 3, we found that the children's first-fixation duration was significantly longer in the high-biophilic-design compared to the low-biophilic-design condition ( $t = 2.435$ ;  $df = 27$ ;  $p \leq 0.005$  Hedges'  $g = 0.905$ ).



**Figure 3.** Length of the first fixations of participants exposed to the high biophilic-design and the low-biophilic-design. \*  $p < 0.05$ , generated by independent  $t$ -test. Error bars depict a 95% confidence interval.

As shown in Table 1, we did not find significant differences in the time to first fixation ( $t = 1.051$ ;  $df = 27$ ;  $p = 0.302$ ), in the fixation count ( $t = 0.255$ ;  $df = 27$ ;  $p = 0.801$ ), or in the total looking time ( $t = 1.793$ ;  $df = 27$ ;  $p = 0.084$ ).

**Table 1.** Mean and standard deviation (SD) of the time to first fixation, the fixation count, and the total looking time in the two conditions: high-biophilic-design and low-biophilic-design.

	Conditions	N	Mean	SD
<b>Time to First Fixation (seconds)</b>	High-biophilic-design	15	0.031	0.072
	Low-biophilic-design	14	0.066	0.10
<b>Fixation Count (frequencies)</b>	High-biophilic-design	15	17.28	3.30
	Low-biophilic-design	14	17.57	2.74
<b>Total Looking Time (seconds)</b>	High-biophilic-design	15	8.99	0.91
	Low-biophilic-design	14	8.24	1.3

#### 4. Discussion

Built and physical environments affect human health and well-being [5,37]. The question of how environments directly affect early learning and cognition in early childhood and infancy remains unanswered. Visual attention drives early learning [38] and communication. Environmental biophilic elements, such as plants in the physical environment, foster wellness [26] and even attention [27]. Here, we investigated how one aspect of high and low degrees of biophilic designs affect visual attention in preschool children. Our findings indicate that the inclusion of plants in the design of indoor spaces in schools has a beneficial effect on visual attention in preschool children. In the high-biophilic-design condition, the children fixated for longer on the images the first time that they saw them on a computer screen. The first-fixation duration is a measure of particular interest in the environment. The first fixation on a visual scene generates an initial representation of the world. This representation orients subsequent eye movements in a task. The eyes explore elements that are known from previous experiences and are related to task instructions or to the observer's goals [39]. For this reason, the first-fixation duration is crucial for the learning process.

Our findings suggest that the placement of plants on desks may enhance visual attention in preschool children. Since the first visual fixation is a key component of the learning process [40], this finding demonstrates the potential of biophilic design to promote successful school days in preschool years. Our results are in line with those of a previous study [18] with adults, which found that the presence of plants in an office space improved cognitive performance and attention capacity. Our findings also point to a methodology with which to further investigate the impact of indoor biophilic design on cognitive performances in young children. As suggested by the Attention Restoration Theory (ART) [30], natural elements, such as plants, might exert a restorative effect on children's attentional capacity. Classically built environments require constant top-down voluntary attention. This results in mental fatigue. Natural elements activate bottom-up involuntary attention, allowing top-down directed-attention abilities to restore. For these reasons, indoor environments can have a restorative effect and help to renew attention [30].

In our study, only the length of the first fixation was significantly longer in the high-biophilic-design condition. The total looking time was not influenced. It is possible that the plants on the desk activated bottom-up processes. The first-fixation duration is free from the voluntary control of the observer. This is because the observer does not know anything about the stimuli before looking at them for the first time. In contrast, refixations on scenes might be influenced by a variety of cognitive processes. These may include memories of visual details that children encode during previous fixations. Subsequent fixations may be influenced by top-down processes, such as previous knowledge and experience [39–43]. Further studies are needed to explore how various stimuli may interact with visual fixations as a function of biophilic design. The elements of biophilic design in our study should have also affected the time to first fixation. The time to first fixation is another measure of bottom-up attention. This was not the case because we introduced a central attractor before every stimulus to control for the latency of fixation toward each stimulus.

Our study has a few limitations that should be addressed. We addressed biophilic design in a limited way. According to Kellert [9], there are several elements of biophilic design that can be incorporated into a given space. Examples include botanical motifs, oval and tubular forms, arches, shells and spirals, natural light, and landscape features. Further studies are needed to explore the possible role of additional elements of biophilic design in attention in children. In addition, here, we focused on the visual modality. The question of how children are affected by biophilic design in the auditory domain remains unanswered. In the low-biophilic-condition, the children did not have the option to look at objects and, therefore, should have looked at the screen for longer. However, this is not what we found. We based our procedure on the study with adults [18], in which there were no objects on the desk in the low-biophilic-conditions. The children might even have been expected to look at the screen for longer in the low-biophilic-condition, given that there



was nothing else for them to look at. Supporting our hypothesis, the participants showed longer first-fixation durations in the high biophilic condition. This suggests that the plants helped the children to focus their visual attention. Remarkably, we found that even short exposures of only 48 s to a plant on a desk increased the children's visual fixation. These results highlight the important role of biophilic design in building design and architecture. Here, we highlight the use of eye tracking as a methodology to research the influence of biophilic design in early childhood. Increasingly, the design of built environments needs to consider biophilic approaches for children [12]. According to StreetEasy, parents are willing to pay a premium for playrooms in urban settings, such as New York City [44].

Many of these playrooms include elements of biophilic design [12]. In addition, other building features, from balconies to acoustics and lighting, are critical to health and well-being [40]. Further research is needed to assess the influence of biophilic design on early cognition and development.

A final limitation is the narrow age range that we tested. Future research should explore the influence of biophilic design in early infancy. Infants show an innate reluctance to explore plants. Wertz and Wynn [45] presented 8–18-month-old infants with two real plants, two realistic-looking artificial plants, and two artifacts. The infants sat on their parents' laps across a table from an experimenter, who placed six objects, one at a time, in front of each infant while saying, "Look what I've got." The infants were reluctant to reach out and touch the plants. This may have been because infants possess strategies to protect themselves from the dangers of poisonous plants. Research is needed to explore how the avoidance of plants develops and how to integrate biophilic design into the homes of infants. Research is also needed to explore how various elements of biophilic design may interact, such as lighting, air, and plants. The amount and quality of biophilic design also need to be considered. It is remarkable that the children in our study responded to simple plants on their desks. The question of whether images of plants would have influenced the children's attention was not addressed. Future research could use virtual reality to begin to address some of these questions [46].

## 5. Conclusions

Biophilic environments promote the positive effect that natural elements have on people's well-being [6,47]. Biophilic environments help humans to foster their relationships with natural elements, which can help recovery from attentional fatigue and stress [48,49].

Here, we demonstrated the beneficial effects of biophilic design on preschoolers' visual attention in indoor environments. Remarkably, we found that even a short exposure, of only 48 s, to plants on a desk increased the duration of the children's first visual fixation to displays of art. Our findings support the Attention Restoration Theory (ART) [30], according to which natural elements activate bottom-up attentional processes. Further research is needed to assess the influence of a wider range of biophilic design elements, such as air quality, sound, and lighting on early cognition and development.

Biophilic environments have the power to restore children's attention [48]. Indoor plants may be considered as restorative elements at school and could even be integrated into science curriculums. Better collaborations are needed among developmental and cognitive scientists, designers, and architects to design optimal environments for living and learning.

**Author Contributions:** T.S., R.F. and H.R. conceptualized the study; T.S., R.F. and S.C. wrote the first draft. R.F. and S.C. collected and analyzed the data; T.S. and H.R. supervised the manuscript. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research did not receive any specific grants from funding agencies in the public, commercial, or not-for-profit sectors.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author.

**Acknowledgments:** We thank the study participants for volunteering their time and all the parents who gave their consent for the children to participate in the research. We also thank Marcella Vacca for hosting the study at the school that she directed and all the teachers for their thoughtful support during the realization of the study.

**Conflicts of Interest:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as potential conflicts of interest.

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