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# The impacts of light color on autistic children

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This study explores light colors' positive and negative effects on children with Autism Spectrum Condition (ASC). This study was conducted under the hard situation of COVID-19. It also demonstrated the possibility of research in unfamiliar and limited situations. Design and environment have a significant effect on ASC. Color, light, and spatial design aspects have been specifically studied before. However, to our knowledge, the color of light's impact on children who are diagnosed with ASC has not been investigated in the literature. This study aims to fill the gap by asking two main research questions: Do participants' behavior change significantly depending on the chosen colors of light? Which colors of light trigger positive and negative behaviors? Empirical research was conducted to answer the research questions. Six colors of light (blue, green, pink, yellow, red, and white light) and six typical behaviors (Playfulness, eye contact, refusal of task, repetitive body movement, repetitive speech, and aggression) were selected. The experiment relied on the observation of participants under different color settings of light. Thirteen children with low to mild levels of ASD, aged between five to eleven participated in this research voluntarily. The findings showed a relationship between the color of light and the behavior of children on the spectrum. It was found that playfulness was observed the most in yellow (84.6%), refusal of the task was most observed in white (38.5%), and eye contact was most observed in yellow (7.7%). Repetitive body movement was most observed in yellow (7.7%) and red light (7.7%). The repetitive speech was the most in red (7.7%) and blue (7.7%) light.

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## Introduction

In 1942, psychiatrist Leo Kanner formulated a novel type of diagnosis as “autistic disturbances of affective contact.” Initially, he observed eight children and made a brief explanation: “The main distinction lies in the inability of these children from earliest infancy to relate themselves to other people.” Kanner added that this inability to relate was present in children whose overall health and ‘intellectual endowment’ was otherwise not significantly impaired. Then the number of cases he was tracking had increased to eleven. Eight of his subjects were boys, and three were girls. It took him four years to observe and discover “autism.”

In 1943, he published an article titled “Autistic Disturbances of Affective Contact.” He would soon replace this term with infantile autism, which meant that the autism was present in the earliest childhood; the children had come into the world with autism. The condition manifested itself early in life and came with its peculiarities, such as flashes of brilliance, distinctive use of language, and a ‘basic desire for aloneness and sameness’ (Donvan et al., 2016).

Autism Spectrum Condition (ASC) includes some impairments in social skills and behaviors. According to DSM-5, individuals on the spectrum can have deficits in social-emotional reciprocity, communication, and maintaining relationships. Moreover, they can have restricted, repetitive patterns of behavior. The severity level of ASC varies. It can be Level 1- Requiring Support, Level 2- Requiring Substantial Support, and Level 3- Requiring very substantial support (DSM-5, 2013).

Individuals on the spectrum have some challenges related to their surroundings. Since they have different perceptions than people who are not on the spectrum. Tola, Talu, Congiu et al. (2021) mentioned that individuals on the spectrum have hyper or hypo-reactivity to sensory input or unusual interest in sensory aspects of the environment (e.g., adverse response to specific sounds or textures, excessive smelling or touching of objects, visual fascination with lights or movement, and light sensitivity).

Light sensitivity in ASC manifests in some ways, depending on the individual. Some common manifestations include discomfort or pain in bright light, difficulty focusing or concentrating in well-lit environments, and an aversion to certain types of lighting, such as fluorescent lights (Golden Care Therapy (2024)). Children on the spectrum are also sensitive to color. Colors in interior spaces affect their mood, learning, and behavior, and must be chosen judiciously (Franklin et al., 2008; Tola et al., 2021).

Color and light effects on children with ASC have been researched before. However, the color of light and its behavioral effects are not studied. Object color and light color effects can have differences in children with ASC. It is significant to test the most mentioned colors in literature for ASC on light, whether the object colors have similarities and differences with the light color. In this way, the effects of light color would be learned. Moreover, this study aimed to fill the gap in the literature by focusing on the color of light and its effect on the behavior of children on the spectrum. Due to infinite color selection and various behaviors, focus is kept within the limit when selecting color and behavior. Six colors of light and six typical behaviors of individuals on the spectrum were selected, depending on the literature to observe. Selected colors and behaviors are the ones that are mostly mentioned in the literature for ASC. The observation was completed in the light of two main research questions as below:

1. Do the behaviors of participants change significantly depending on the chosen colors of light?
2. Which colors of light trigger positive and negative behaviors?

The article is designed as follows: 1st section is Introduction. 2nd section is Color, Light, and ASC explains the literature review

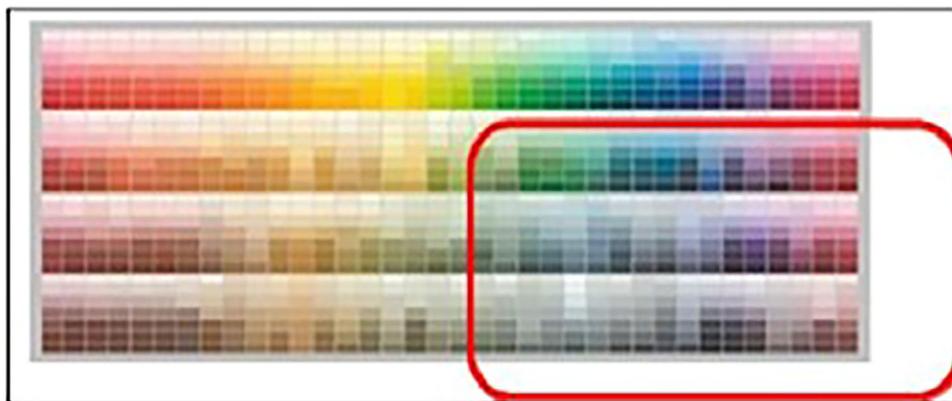
on lighting and color for ASC. 3rd section is Materials and Methods, which displays the research procedure, enrollment of participants, and selection of lighting, color, and behavior codes. 4th section is the Findings part that indicates the effect of light color and behavior of children on the spectrum. The next section is the 5th Analysis section, which analyses the data to comprehend the relation between light color and the behavior of children on the spectrum broadly. The 6th section is the Conclusion, which sums up all the information and suggests further approaches for researchers.

## Color, light, and ASC

Light is not only related to physiology but also it is related with psychology. It can improve mood and stabilize our circadian rhythms, helping us get a better and deeper night’s sleep (Blume, Garbaza & Spitschan, 2019). Rachel and Stephen Kaplan, both former professors of psychology at the University of Michigan, have conducted much research about the environment and psychology. Kaplan and Kaplan (1989) found that when we are exposed to a new environment, we try to find a match in our memory that fits the new environment. At that point, light plays a significant role in highlighting building elements, spaces, and textures. For instance, some researchers have measured the effect of the color of the lights on the brain. They found that blue and alternate light stimulates and strengthens the relationship between brain regions involved in emotions and language processing. Also, it can make individuals feel more energetic (Tracey-Clayton, 2020).

Vision is crucial for everybody. However, the visual perception can vary from person to person. It depends on the features of humans and how he or she can perceive, process, and respond to the information. Lighting shapes perception and experience. Due to the Sensory Processing Disorder (SPD) individuals on the spectrum can have sensory perception anomalies (APA, 2013). The brain does not process sensory inputs correctly, so there can be inappropriate or abnormal perception, and behavioral and motor responses (Simal et al., 2020). Abnormal visual perception starts in early childhood (Zhou et al., (2023)). Visual anomalies include aimless visual exploration of a new environment (Man'yakov et al., 2018); lack of visual fixation for meaningful social stimuli, and difficulty diverting or disengaging vision (Shirama et al., 2016); appear to read jumper, the opposite direction of writing, up and down stairs space sense abnormal visual space perception abnormality (Wainwright, Bryson (1996)). The altered perception may cause sensory overload for some individuals on the spectrum, which leads them to negative emotional and behavioral responses due to stress and fear (Canavan, 2015). Moreover, the sensory overload around them can cause some behaviors such as lack of eye contact, staring at spinning objects or light, fleeting peripheral glances, side viewing, and difficulty attending visually (Covd, 2020).

Autism Spectrum Condition does not have only one type. Therefore, the five senses of perception vary if the individual bears symptoms of hypersensitivity or hyposensitivity. When an individual has a hypersensitive type of ASC, which means this person may have a hypervision. Hypervision means their vision is so acute that they can even complain about bright lights, sharp flashes, and the tiniest pieces of fluff on the carpet that are perceived as air particles (Bogdashina, 2011). It may be stemming from sensory overload. Bright lights, fluorescent lights, and sunlight cause sensory overload. Fluorescent lighting has been linked to hypertension, headaches, insomnia, and interference with calcium absorption in the general population (Torrice & Logrippo, 1989). Therefore, some lighting types can disturb them.



**Fig. 1** Chosen color palette by children on the spectrum (The Land of Color, 2013).

Bogdashina (2011) noted that ‘under fluorescent lights, children who have hypersensitive features of Autism Spectrum Condition can see a 60-cycle flickering: the whole room pulsates on and off’. To understand hyposensitive people with ASC, it is needed to understand how their sight is affected. It is indicated that individuals can only see the outlines of objects, and have behaviors such as children repeatedly moving their hands over objects, exploring everything in an unfamiliar place by touching it, repeatedly moving their hands and toys in front of their eyes, a love for bright lights, sunlight, bright colors and reflections, and an inability or difficulty to control their eye movements and to track moving objects (Newautismcure, 2019).

There is a link between the type of lights and repetitive behaviors of individuals on the spectrum. It is found that fluorescent light increases repetitive behavior (Colman, Frankel, Ritvo, & Freeman, 1976, 157), arousal (Baumeister, Forehand (1973), 586), and hyperactivity. (Ross & Ross, 1976) and causes migraines and/or epilepsy, tantrums. Furthermore, it is significant to consider that not every person who is diagnosed with ASC is the same. Some can bear hypersensitive features of ASC, and some can bear hypo-sensitive features. Gaines et al., 2016 state that hypo-sensitive autistic individuals can only see outlines of certain objects, and they like bright colors and bright sunlight. Yet, hypersensitive autistic individuals are bothered by bright lights and easily distracted by movement. Therefore, control of lighting is essential regarding sensory differences. Incandescent lamps provide users with a high level of dimming control and emit a warm color (Long, 2010, p. 24). Especially in classrooms, it is important to prevent noise that is sourced from ballast and lamp flicker.

Another vital factor in lighting design is color temperature. “The color temperature of a light source is the temperature of an ideal black-body radiator that radiates light of comparable hue to that of the light source” (Choudhury (2014), p. 1). It is recommended that the color temperature of the lamp source should be 3000 K to 3500 K to generate a warm color temperature (Long, 2010, p. 46).

Color and light have an interlinked relationship. Shareef & Farivarsadri, 2018 investigated the role of color and light on children’s perception of the spectrum. In this way, researchers indicated the most preferred colors and lights. The methodology of the study was a comparison between the obtained data from the literature review and a case study, which was realized as a part of the research and evaluation of all the results together. The case study’s participant group was special education teachers. In this study, 31 teachers participated. In the first phase of this study, a set of colors (red, yellow, gray, green, blue, and white) was shown to the participants, and they were asked to separate the positive

and negative colors for children with ASC, depending on their observation. White, Green, Blue, and Gray were categorized as positive colors. Yellow and red colors were grouped as negative colors. They also preferred secondary and intermediate cold colors as well as dull or pale colors (Shareef & Farivarsadri, 2018, Fig. 1). This demonstrates that they perceive strong saturated colors negatively.

Cherry, Underwood (2012) mentioned about known effect of color on humans that depends on past experiences. She illustrates the effects of different colors on human perception below:

1. Red: Stimulates the mind and increases appetite and blood circulation.
2. Bright yellow: Overstimulates and reflects light.
3. Pale yellow: Causes calming in the mind.
4. Blue: Reduces blood pressure and keeps calm.
5. Green: Related to nature and inspiration, soothing.
6. Orange: Disturbance and overstimulation.
7. Rose or light pink: Soothing (Cherry, Underwood (2012))

Turner, who is an interior designer and colorist, explains ASC and color relationship broadly in her blog (2017). She did not test her outcome of the color and ASC relationship. However, based on her experience and past knowledge, she summarizes how specific colors affect individuals on the spectrum. Moreover, color has some significant effects on individuals on the spectrum as described below (Turner, 2018).

1. Red: It can be perceived as too bright and intense. Therefore, it is challenging for individuals on the spectrum.
2. White: It reflects the surrounding colors. It can cause eye fatigue and disturbance.
3. Green: It is the safest color selection for individuals on the spectrum. The green, brings harmony and balance to the environment. It has a positive effect on individuals on the spectrum.
4. Blue: It has a soothing effect. It will not affect individuals on the spectrum negatively in terms of their senses.
5. Monochromatic Color: It describes the saturation of a color. Monochromatic color has a positive effect on individuals on the spectrum.

There is another scientific research on color and autism that depends on a quantitative research model. In this research, a questionnaire survey was conducted at an autism center among autistic children and their parents. This study included children on the spectrum aged between 6 and 16 (45 males, 42 females, mean age 8.7 years, standard deviation 2.3) (Nair et al., 2022). A color matrix was prepared to understand which color makes autistic children feel/comfortable/calm/agitated (Fig. 2).

1	10	19	28	37	46	55	64	73	82	91	100	109	118	127	136	145	154	163	172
2	11	20	29	38	47	56	65	74	83	92	101	110	119	128	137	146	155	164	173
3	12	21	30	39	48	57	66	75	84	93	102	111	120	129	138	147	156	165	174
4	13	22	31	40	49	58	67	76	85	94	103	112	121	130	139	148	157	166	175
5	14	23	32	41	50	59	68	77	86	95	104	113	122	131	140	149	158	167	176
6	15	24	33	42	51	60	69	78	87	96	105	114	123	132	141	150	159	168	177
7	16	25	34	43	52	61	70	79	88	97	106	115	124	133	142	151	160	169	178
8	17	26	35	44	53	62	71	80	89	98	107	116	125	134	143	152	161	170	179
9	18	27	36	45	54	63	72	81	90	99	108	117	126	135	144	153	162	171	180

Fig. 2 Color matrix. (Nair, et al., 2022).

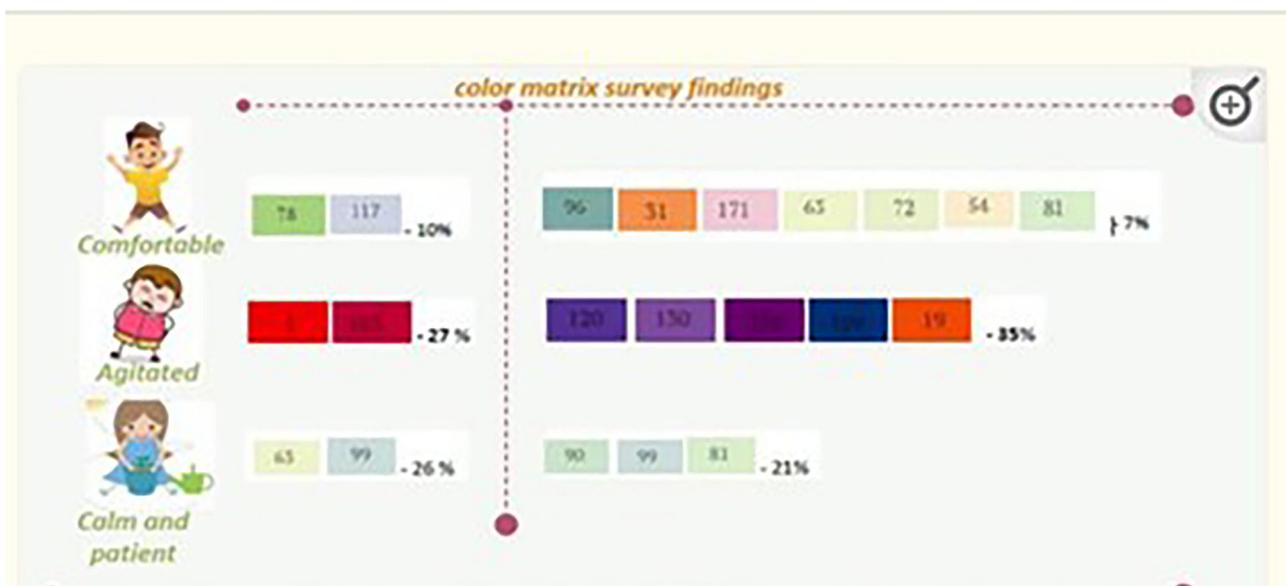


Fig. 3 Color matrix survey finding (Nair et al., 2022).

Depending on 87 participants’ answers, it is found that blue, green, and their tones were considered comfortable for individuals on the spectrum. Red and its tones were perceived as agitated. Lastly, yellow, blue, and their tones were considered calm and patient colors (Fig. 3).

Furthermore, color is significant in terms of the senses. Masataka and Grandgeorge conducted comparative research between typically developed children and children on the spectrum. The research age group was between 4 to 7, 8 to 10, and 11 to 17. It was found that blue, brown, and green were the most preferred colors among the ages between four to seven. The colors blue and red are the most commonly chosen by children aged eight to 10. Blue was the most preferred among the ages of 11 to 17. The least chosen color was pink in all age groups (Grandgeorge & Masataka, 2016, p.1).

**Materials and methods**

Color and light’s effect on individuals on the spectrum were studied in this study. The empirical research method was applied in this study to gain quantitative data. Therefore, the effect of six different colors of light (blue, green, yellow, red, white, and pink) and six different behaviors (playfulness, eye contact, refusal of

task, repetitive body movement, repetitive speech, and aggression) children on the spectrum was researched. Each behavior was observed in each color of light for 10 min. In total, the test took one hour for each participant. Research took place at Ball State University’s Health and Environmental Design Laboratory. It was funded by the Turkish Scientific and Technological Research Council (TUBITAK) for a 6-month research period. Research started on the 1st of February 2021 and ended on the 31st of July 2021. Actually, research scholarship was for 2020. 2020 was the year that COVID-19 hit the whole world. Thus, the research time was postponed. COVID-19 continued for a long time with an unpredictable timeline. It was not possible to postpone the research time due to the period of scholarship and Ph.D. Due to COVID-19, this research was done under limited and hard conditions. Thus, only 13 autistic children participated in this study. To conduct this study, empirical research method was applied.

**Sampling and enrollment of participants.** After selecting the color of light, the next step was to enroll participants in this study. In this study, some communities were involved, such as the Behavior Associates Clinic in Muncie, Indiana, and the Ball State

University Communication Center. Research flyers were prepared to provide the families of participants with information. After the announcement, 13 children on the spectrum were found. 61.50% of the participants were boys, and 53.86% of them were in elementary school. 30.76% of the participants were seven years old (Table 1). Also, 76.90% had a low level of ASC (Table 1). ASC levels of participants were assessed by the declaration of the participants' parents, which was diagnosed by the doctors. The research sample was based on Purposive Sampling. To participate in this study, target participants needed to be diagnosed with ASC, which can vary from low to mild levels of ASC. 13 children (between the ages range from 5 to 11) on the spectrum, whose symptoms range from low to mild levels, participated in this study. To complete the test, all participants needed to be reachable in terms of senses and their cognitive abilities. Therefore, participants were selected from the group of children on the spectrum without any vision, mental, or sensory anomalies.

**The light color description and selection.** The selection of color was made depending on the literature (see Turner, 2018; Cherry, Underwood (2012); Nair et al., 2022), and six different colors of light were divided according to their positive and negative effects. The effects of colors' positivity and negativity on children with ASC were obtained from the search on existing literature. According to the literature, positive and negative color groups and their sources can be seen below.

*Positive color group*

**Blue:** It is stated that blue and green colors are mostly selected by individuals on the spectrum (Masataka and Grandgeorge, 2016; GA Architects, n.d.).

**Green:** The suitability of blue and green colors for individuals on the spectrum was mentioned in this research, which was done in collaboration with GA Architects and Kingston University (GA Architects, n.d.).

**Pink:** Pink has a positive effect on children who are diagnosed with ASC (Moffit, 2018).

*Negative Color Group*

**Red:** Red is the dominant color. Therefore, it can be perceived as a very bright and intense color. It can be challenging for individuals on the spectrum and can cause aggression (Turner, 2018).

**Yellow:** Architect Cathy Cherry mentioned that especially bright yellow can negatively affect individuals on the spectrum (2012). That is why she suggested not to use yellow when designing for individuals who are diagnosed with ASC.

**White:** Interior architect and color expert Denise Turner states that the color of white causes eye strain due to its feature of reflectiveness for individuals on the spectrum (2018).

**Table 1 Sample.**

Participant	Type	Number	Percentage (%)
Gender	Boy	9	61.50
	Girl	4	38.50
Education Level	Kindergarden	6	46.14
	Elementary	7	53.86
Age	5	3	23.07
	6	3	23.07
	7	4	30.76
	8	0	0
	9	0	0
	10	2	15.41
	11	1	7.69
ASC Level	Low	10	76.90
	Mild	3	23.10

**Table 2 Behavior Codes.**

Behavior Codes	Definition
Playfulness	It is an experience of playing. At this point, the function of the game is not the main part. The central part is to experience the playing. Playing games is helpful for children to develop their creativity, social abilities, and solve their daily life problems. According to Skaines, Rodger, and Bundy, children on the spectrum play games less than typically developed children (2016). Under which factors does playfulness increase is unknown.
Eye Contact	Individuals on the spectrum usually have difficulty in terms of eye contact. Not all individuals on the spectrum are the same. Some can easily have eye contact, but others can avoid it. The average length of the single periods of eye contact varied from 1.7 to 3.6 s (Hietanen, J.K et al., 2016). In this research, one single instance of eye contact is not considered an act of eye contact. However, its duration was taken into consideration. Eye contact was counted if the participant continued eye contact for more than 1.7 s (Hietanen, J.K et al., 2016).
Aggressive Behavior	This is a group of behavior that includes some harmful behaviors, such as hitting, kicking biting, verbal aggression, and injuring self or others. Michelle Turner mentioned that hitting can cause serious results, such as tissue damage and open wounds (1999).
Refusal of Task	It is an expression of boredom (Jahromi, Meek, & Ober-Reynolds, 2012). As a result, individuals leave what she or he is doing as a task. This behavior is usually seen in the environment of classrooms. Refusal of task is the behavior of withdrawing from the task due to the emotional state of individuals. That means, it is regardless of the difficulty of the task. In this study, participants were asked to pick up one of the activities, such as drawing, or doing a puzzle. Each participant is observed while doing the selected activity under different colors of light. Observation helped perceive the maintenance of the game and the act of play under certain colors of light.
Repetitive Movement	Repetitive movement is a set of behaviors that includes the movement of parts of the body or arms in a repetitive state (National Institute of Mental Health, 2013). For instance, repetitive movement can be a child's constant clapping or spinning around. In the behavioral observation process, the color of light and repetitive movement relationship is perceived. Behavioral observation helped the researcher determine if a specific light color triggered or soothed repetitive movement.
Repetitive Speech (Echolalia)	Repetitive speech seems to affect individuals on the spectrum frequently. Individuals can often repeat some words or groups of words. In this study, repetitive speech and its frequency are observed. If repetitive speech is detected, its connection with the color of light is observed.

**Behavioral observation and the creation of behavioral codes.** In this study, typical behaviors were selected according to the literature, which was mentioned mostly (Turner, 1999; Skaines et al., 2006) The behavioral codes were grouped into positive and negative behaviors. Negative behaviors were aggression, repetitive body movement, repetitive speech (echolalia), and refusal of a task. Positive behaviors were eye contact and playfulness. These behaviors were common for children on the spectrum. Negative and positive types of behaviors can be seen frequently in children on the spectrum. It affects their education and their daily lives. These behavior codes for light color observation had not been utilized by any researcher before. Selected behavioral codes are explained below (Table 2).

**Description of research environment and procedure.** This research took place in the Health and Environmental Design Research (HEDR) Lab. The lab had an observation, research, waiting, and playing area. The waiting and playing area takes place in the same area. The waiting area was for people who were accompanying participants. The waiting area can be used by participants and their companions. Also, in the playing area, research

participants can take a break. There was a camera in the observation room to make observations. Also, the observation room has a light meter and a sound level meter to make measurements.

In the test room, a camera was set to observe behavior and save the behavior on the software. The names of the software used are AcqKnowledge and The Observer. Observation was saved in AcqKnowledge and the Observer. Both software programs worked in coordination to reach quantitative data. The Observer software helps see the mimics and gestures of each participant via the camera in the test room. In this way, it was easy to detect behaviors, such as playfulness and aggression. Acqknowledge helped turn observation into quantitative data by saving how many times the behavior was observed (Fig. 4). After setting all the behavior codes on the Observer, each participant was observed under the six different colors of light (Figs. 5–10). 10 min were given for each color of light. The color of the light observation is the same for every participant. It started with blue light, continued with green, pink, yellow, and red lights, and ended with white light (Figs. 5–10). If a certain behavior code was observed, the researcher clicked on a certain behavior code in the software. The duration of this research was counted in

	A	B	C	D	E	F	G	H	I	J	K
	Date_Tim	Date_dmn	Time_Abs	Time_Abs	Time_Rel	Time_Rel	Time_Rel	Time_Rel	Observati	Behavior	Comment
	#####	#####	16:28:14	965,204	#####	00:00:00	0	0	Observati		
	#####	#####	16:28:15	965,204	#####	00:00:01	0	1	Observati		
	#####	#####	16:28:16	965,204	#####	00:00:02	0	2	Observati		
	#####	#####	16:28:17	965,204	#####	00:00:03	0	3	Observati		
	#####	#####	16:28:18	965,204	#####	00:00:04	0	4	Observati		
	#####	#####	16:28:19	965,204	#####	00:00:05	0	5	Observati		
	#####	#####	16:28:20	965,204	#####	00:00:06	0	6	Observati		
	#####	#####	16:28:21	965,204	#####	00:00:07	0	7	Observati		
0	#####	#####	16:28:22	965,204	#####	00:00:08	0	8	Observati		
1	#####	#####	16:28:23	965,204	#####	00:00:09	0	9	Observati		
2	#####	#####	16:28:24	965,204	#####	00:00:10	0	10	Observati		
3	#####	#####	16:28:25	965,204	#####	00:00:11	0	11	Observati		
4	#####	#####	16:28:26	965,204	#####	00:00:12	0	12	Observati		
5	#####	#####	16:28:27	965,204	#####	00:00:13	0	13	Observati		
5	#####	#####	16:28:28	965,204	#####	00:00:14	0	14	Observati		
7	#####	#####	16:28:29	965,204	#####	00:00:15	0	15	Observati		
3	#####	#####	16:28:30	965,204	#####	00:00:16	0	16	Observati		
9	#####	#####	16:28:31	965,204	#####	00:00:17	0	17	Observati	playfulne	
0	#####	#####	16:28:32	965,204	#####	00:00:18	0	18	Observati		
1	#####	#####	16:28:33	965,204	#####	00:00:19	0	19	Observati		
2	#####	#####	16:28:34	965,204	#####	00:00:20	0	20	Observati		
3	#####	#####	16:28:35	965,204	#####	00:00:21	0	21	Observati		
4	#####	#####	16:28:36	965,204	#####	00:00:22	0	22	Observati		
5	#####	#####	16:28:37	965,204	#####	00:00:23	0	23	Observati		
5	#####	#####	16:28:38	965,204	#####	00:00:24	0	24	Observati		
7	#####	#####	16:28:39	965,204	#####	00:00:25	0	25	Observati		
3	#####	#####	16:28:40	965,204	#####	00:00:26	0	26	Observati		
9	#####	#####	16:28:41	965,204	#####	00:00:27	0	27	Observati		
0	#####	#####	16:28:42	965,204	#####	00:00:28	0	28	Observati		
1	#####	#####	16:28:43	965,204	#####	00:00:29	0	29	Observati		
2	#####	#####	16:28:44	965,204	#####	00:00:30	0	30	Observati		
3	#####	#####	16:28:45	965,204	#####	00:00:31	0	31	Observati		
4	#####	#####	16:28:46	965,204	#####	00:00:32	0	32	Observati	playfulne	
5	#####	#####	16:28:47	965,204	#####	00:00:33	0	33	Observati		

Fig. 4 An example of merged data of a color and behavior observation.



**Fig. 5** Settlement 1- Blue.



**Fig. 9** Settlement 5- Red.



**Fig. 6** Settlement 2- Green.



**Fig. 10** Settlement 6- White.



**Fig. 7** Settlement 3- Pink.



**Fig. 8** Settlement 4- Yellow.

Acqknowledge after each test. The Observer's data were merged. As a result, the researcher could learn how often the selected behavior was seen under a specific color of light.

**The activities of participants during the test.** Before the test, participants were asked to choose a puzzle, play dough, or

drawing tools (crayons, paper). During the test, participants were busy with the chosen task. Therefore, observation were performed in the natural setting of the participants. Parents or accompanys of participants accompanied the participants. Parents or accompanys of participants waited for participants in the waiting room during the test. However, in the test room, participants needed to be alone to have an accurate observation.

**Findings**

In the scope of this research, 13 children were observed. Data were analyzed using frequency, percentage, and cross-table. However, chi-square analysis could not be performed because the number of cells with the expected value below 5 was over 20% (Büyükoztürk, 2021). IBM SPSS 26 software was used to analyze the data.

Each color of light was shown to each participant, and the observed behavior was saved on the software (The Observer). Every color of light observation time was 10 min, as mentioned previously (Section 3). In total, the test took an hour without any breaks. This study defined variables as six behaviors and six colors of light. Each participant's behavior was observed. After that, the most observed behavior under specific light color was identified (Table 16). Also, age and gender based analysis were also conducted (Tables 3 and 4).

It was noticed that behaviors vary according to age (Table 3). For instance, at age five, playfulness was seen mainly in green light. Refusal of the task was primarily observed in pink light. Eye contact was primarily observed in pink light. Repetitive body movement and repetitive speech were observed most in the red light. Aggression was observed most in the white light. At the age of six, playfulness and eye contact were observed in pink the most. Refusal of the task was observed most in white light. Repetitive body movement was mostly observed in white light. Repetitive speech was observed most in blue and green light. Aggression was seen most in white light.

**Table 3 Behaviors according to the ages.**

Behavior								
Color	Age	Playfulness (Avg. %)	Refusal of Task (Avg. %)	Eye Contact (Avg. %)	Repetitive Body Movement (Avg.%)	Repetitive Speech (Avg. %)	Aggression (Avg. %)	
Blue	5	56.45	15.1	11.77	11.39	2.38	2.38	
	6	13.15	40.81	0	3.03	31.47	0	
	7	51.49	29.14	2.17	6.25	3.56	1	
	10	41.6	0.4916	0.0416	0.045	0	0	
	11	53.64	5.30	25.83	15.23	0.00	0.00	
Green	5	66.66	14.28	2.38	4.76	9.52	2.38	
	6	13.15	40.81	0	3.03	31.47	0	
	7	47.56	35.09	6.92	1.19	5.95	3.27	
	10	0.7329	0.356	0.1087	0	0.0435	0.0416	
	11	63.38	19.72	14.08	2.82	0.00	0.00	
Pink	5	32.85	37.88	13.09	6.66	9.52	2.38	
	6	86.54	6.73	6.73	0	0	0	
	7	77.71	33.8	14.48	10.57	0	0.5	
	10	0.3566	34.09	0.0384	0	0	0	
	11	95.69	0.00	4.31	0.00	0.00	0.00	
Yellow	5	39.88	32.44	11.01	4.16	6.25	6.25	
	6	67.42	20.95	5.55	0	6.06	0	
	7	49.8	33.12	4.99	12.07	0	0	
	10	0.73085	0.1943	0.1959	0.0058	0	0	
	11	55.56	4.09	39.18	1.17	0.00	0.00	
Red	5	16.19	31.03	5.56	18.96	28.25	0	
	6	65.29	20.75	3.33	4.16	5.37	1.07	
	7	47.65	17.66	7.03	3.03	13.18	11.43	
	10	0.4065	0.4558	0.094	0	0	0.0454	
	11	46.53	34.65	18.21	0.00	0.00	0.00	
White	5	24.81	28.33	8.33	10.37	8.33	19.81	
	6	40.19	44.38	4.13	8.89	0	4.94	
	7	48.14	33.55	3.7	9.55	0	5.04	
	10	0.1824	0.276	0	0.0756	0	0.0625	
	11	50.00	9.09	37.22	3.03	0.00	0.00	

**Table 4 Behaviors according to Gender.**

Behavior							
Color	Gender	Playfulness (Avg. %)	Refusal of Task (Avg. %)	Eye Contact (Avg. %)	Repetitive Body Movement (Avg.%)	Repetitive Speech (Avg. %)	Aggression (Avg. %)
Blue	Boy	14.7	31.31	6.81	9.41	9.48	1.96
	Girl	49.61	16.92	3.33	0	10.25	0
Green	Boy	14.90	26.64	12.06	3.18	6.10	2.02
	Girl	84.12	4.76	0	1.58	7.93	1.58
Pink	Boy	59.52	22.56	7.67	6.23	3	0.90
	Girl	55.73	29.27	14.99	0	0	0
Yellow	Boy	51.99	26.66	9.57	6.19	3.69	1.87
	Girl	67.64	26.40	5.95	0	0	0
Red	Boy	44.78	27.24	9.92	7.31	10.41	5.44
	Girl	41.88	29.19	8.58	2.77	16.48	1.07
White	Boy	40.49	30.55	11.25	6.56	1.5	9.63
	Girl	23.04	54.38	5.71	11.14	3.33	2.38

**Table 5 Blue Color's Test.**

Reliability Statistics		
Cronbach's Alpha	Cronbach's alpha Based on Standardized Items	N of Items
0.659	0.563	6

At the age of seven, it was noticed that playfulness was primarily observed in pink light. Refusal of the task was observed most in the green light. Eye contact was seen most in pink light. Repetitive body movement was observed most in yellow. Repetitive speech and aggression were observed most in the red light.

At the age of 10, playfulness was mostly observed in blue light. Refusal of the task was most in pink. Eye contact was mostly observed in yellow. Repetitive body was most in blue.

**Table 6 Blue Color's Test.**

Item Statistics			
Mean		Std. Deviation	N
Aggression	0.38	1.121	13
R. Speech	1.92	3.303	13
R. Body	2.69	6.330	13
Eye Contact	3.62	10.666	13
Ref. Task	6.08	5.664	13
Playfulness	13.31	20.978	13

**Table 10 Pink Color's Test.**

Item Statistics			
Mean		Std. Deviation	N
Playfulness	13.62	24.908	13
Ref. Task	3.85	4.543	13
Eye Contact	1.54	2.066	13
R. Body	1.00	3.055	13
R. Speech	0.23	0.832	13
Aggression	0.15	0.555	13

**Table 7 Green Color's Test.**

Reliability Statistics		
Cronbach's Alpha	Cronbach's alpha Based on Standardized Items	N of Items
0.431	0.576	6

**Table 11 Yellow Color's Test.**

Reliability Statistics		
Cronbach's Alpha	Cronbach's alpha Based on Standardized Items	N of Items
0.574	0.370	6

**Table 8 Green Color's Test.**

Item Statistics			
Mean		Std. Deviation	N
Playfulness	11.85	11.452	13
Ref. Task	4.54	5.043	13
Eye Contact	2.00	3.109	13
R. Body	0.54	0.776	13
R. Speech	1.23	2.048	13
Aggression	0.38	0.650	13

**Table 12 Yellow Color's Test.**

Item Statistics			
Mean		Std. Deviation	N
Playfulness	16.54	24.487	13
Ref. Task	5.62	4.464	13
Eye Contact	6.23	18.304	13
R. Body	1.38	3.863	13
R. Speech	0.38	0.961	13
Aggression	0.23	0.832	13

**Table 9 Pink Color's Test.**

Reliability Statistics		
Cronbach's Alpha <sup>a</sup>	Cronbach's alpha Based on Standardized Items	N of Items
-0.062	0.315	6

**Table 13 Red Color's Test.**

Reliability Statistics		
Cronbach's Alpha	Cronbach's alpha Based on Standardized Items	N of Items
0.649	0.424	6

Repetitive speech was seen most in green. Aggression was observed most in red. Depending on the data of the age of 11, playfulness was seen most in pink light. Eye contact was observed most in yellow light. Refusal of task was seen most in red light, and repetitive body movement was seen most in blue light. Repetitive speech and aggression were not observed at the age of 11. There were no participants at the age of eight and nine. Therefore, these age groups cannot be evaluated.

Depending on gender evaluation (Table 4), it seemed that boys have playfulness behavior the most in pink and girls displayed the most in green light. Eye contact was mostly observed in green for boys and in pink for girls. Refusal of the task was primarily observed in white color for the boys and girls. Repetitive body movement was mostly observed in blue for boys and white color on girls. Repetitive speech was primarily observed in red for boys and girls. Aggression was mostly observed in white boys and girls.

ASC Levels: Children who were diagnosed with low levels of ASC displayed playfulness behavior the most in green and pink light. The children who had mild levels of ASC displayed playful behavior in white, pink, and green light. Eye contact was primarily observed in pink for low levels of ASC. However, for the

participants with mild levels of ASC, eye contact was dominant in yellow, pink, and red light. Refusal of the task was seen mostly in white and blue for the low level of ASC, and in green and white for the mild level of ASC. Repetitive body movement was primarily observed in blue, white, and green for low levels. For the mild level of ASC, repetitive body movement was mostly observed in yellow, white, and red. Repetitive speech was seen mostly in green for the low level and dominant in red for the mild level. Lastly, aggression was primarily observed in red and white for low levels. For the mild level, aggression was seen most in white.

To measure data consistency and reliability correlation test was administered. Terzi (2019) stated if Cronbach's level is  $0.00 \leq \alpha < 0.40$  = scale is not reliable, if it is between  $0.40 \leq \alpha < 0.60$  = scale has low reliability; if it is  $0.60 \leq \alpha < 0.80$  = quite reliable;  $0.80 \leq \alpha < 1.00$  = scale has high reliability. Colors reliability tests can be observed in Tables 5 to 15.

**Analysis**

The distribution of the most observed behaviors of the participants according to six different colors is given in Table 17. To

answer the research question, six different colors of light were shown to each participant while they were performing a task, such as drawing, playing, or reading. Since the number of observations made for individuals was not equal, each individual was evaluated in more detail on its own. Color-behavior cross-tabulation was created separately for each individual. Six different colors of light were shown to each participant to determine if the typical behavior of an autistic individual would be observed or not.

**Table 14 Red Color's Test.**

Item Statistics			
Mean		Std. Deviation	N
Playfulness	11.23	11.840	13
Ref. Task	7.46	9.134	13
Eye Contact	2.15	5.210	13
R. Body	0.92	1.498	13
R. Speech	2.46	3.711	13
Aggression	1.08	2.019	13

**Table 15 White Color's Test.**

Reliability Statistics		
Cronbach's Alpha	Cronbach's alpha Based on Standardized Items	N of Items
0.607	0.428	6

**Table 16 White Color's Test.**

Item Statistics			
Mean		Std. Deviation	N
Playfulness	11.69	17.604	13
Ref. Task	7.00	4.243	13
Eye Contact	5.23	13.553	13
R. Body	1.54	1.613	13
R. Speech	0.31	0.855	13
Aggression	1.23	1.641	13

The most experienced behavior by each participant was given a value of 1. If the behavior is not seen in the observed light color, it is given a value of 0. The numbers corresponding to the behavior in Table 16 indicate the behavior that the number of participants experienced most, according to the observed light color. For instance, according to the first row of Table 16, the participant experienced playfulness nine times, refusal of task three times, repetitive body movement four times, and repetitive speech one time. The percentage of participants' behaviors was demonstrated in the first row (ex, Table 17, 69,2%). In this way, the most experienced behavior according to the color of light can be perceived.

As shown in Table 17, the most common behaviors that were observed in all participants. The most common behaviors in blue light were playfulness (69.2%), followed by refusal of task (23.1%), and repetitive speech (7.7%). Eye contact, repetitive body movements, and aggression were not observed in blue light (0%).

During the observation of green light, the most common behaviors were playfulness (69.2%), followed by the refusal of the task (23.1%) and eye contact (7.7%). Repeated body movements, repetitive speech, and aggression were not recognized in the green light (0%). The third behavioral observation was done on pink light. The most common behavior in pink light was playfulness (69.2%), followed by refusal of the task (30.8%). Eye contact, repeated body movements, repeated speech, and aggression were not noticed in pink light (0%).

Throughout the observation of yellow light, playfulness (84.6%) was the most exhibited behavior. Repetitive body movements (7.7%) and eye contact (7.7%) were observed. Refusal of task, aggression, and repetitive speech were not observed (0%). It is noticed that in the red light, playfulness (61.5%), refusal of task (23.1%) behaviors took place the most. Repetitive body movements (7.7%) and repetitive speech (7.7%) were seen. Eye contact and aggression were not observed behaviors (0%). During the observation of white light, it was noticed that the most common behaviors were playfulness (53.8%), followed by refusal of task (38.5%), and aggression (7.7%). The behaviors that were not observed were repetitive body movements, repetitive speech, and eye contact (0%).

Moreover, when the inter-reliability test was considered, it was noticed that some colors need to be omitted. For instance, blue color's Cronbach's alpha was 0.65, which demonstrates that the data were quite reliable. Green color's test analysis demonstrated low reliability (Table 7). Also, as shown in Table 9, it can be seen that for the pink color, it was hard to mention reliability. On the

**Table 17 The Most Observed Behavior of All Participants' on Six Different Colors of Light.**

		Behavior						
		Playfulness	Refusal of Task	Eye Contact	Repetitive Body Movement	Repetitive Speech	Aggression	Total
Color	Blue	<i>n</i> 9	3	0	0	1	0	13
		% 69.2	23.1	0.0	0.0	<b>7.7</b>	0.0	100.0
Green	<i>n</i> 9	3	1	0	0	0	0	13
		% 69.2	23.1	7.7	0.0	0.0	0.0	100.0
Pink	<i>n</i> 9	4	0	0	0	0	0	13
		% 69.2	30.8	0.0	0.0	0.0	0.0	100.0
Yellow	<i>n</i> 11	0	1	1	0	0	0	13
		% 84.6	0.0	7.7	7.7	0.0	0.0	100.0
Red	<i>n</i> 8	3	0	1	1	0	0	13
		% 61.5	23.1	0.0	7.7	7.7	0.0	100.0
White	<i>n</i> 7	5	0	0	0	0	1	13
		% 53.8	38.5	0.0	0.0	0.0	7.7	%100.0
Total	<i>n</i> 53	18	2	2	2	1	78	
		% 67.9%	23.1	2.6	2.6	2.6	1.3	100.0

other hand, the yellow color had reliability. Red and white colors' data were quite reliable as well. Therefore, green and pink were omitted due to their unreliability.

As a result of this analysis, behaviors were grouped into two which are positive and negative behaviors. Positive behaviors, such as playfulness and eye contact, are expected from children on the spectrum to have a better education. Negative behaviors are repetitive body movements, repetitive speech, and refusal of task that may affect the process of education negatively. It was noticed that negative behaviors were mitigated after turning off certain colors of light (red and white). Also, after inter-reliability test analysis, it is more appropriate to take into consideration the colors that have better inter-reliability test results. Therefore, it can be said that playfulness (84,6%) and eye contact (7,7%) were observed most in yellow light. Refusal of the task was seen most in the white color of light (38,5%). Repetitive body movement was recognized mostly in the yellow (7,7%) and red (7,7%) colors of light. Moreover, repetitive speech was recognized mostly in the red (7,7%) and blue (7,7%) color of light.

Lastly, when a comparison was made according to the literature and this study, it was found that there are some similarities and differences in terms of results. The literature mentioned that blue and its tones are considered comfortable colors for individuals on the spectrum. Red and its tones are perceived as agitated. Yellow, blue, and their tones are considered calm and patient colors (Nair et al., 2022, see section 2). In this research, playfulness (84,6%) and eye contact (7,7%) are mostly observed under the yellow light (Table 17). Therefore, this research has similarities with Nair et al., 2022 research in terms of considering yellow as a positive color. However, there is a discrepancy with architect Cathy Cherry's color suggestion. She mentioned that especially bright yellow can affect individuals on the spectrum negatively (Cherry, Underwood (2012)).

Depending on the experiment's result, the red color of light increased negative behaviors, such as refusal of the task (23,1%). Red color's negative effect in research was supported by Nair et al., 2022 study, which mentioned red color as agitated (Nair et al., 2022). Also, in yellow, positive behaviors, such as eye contact and playfulness were increased. That is why Nair et al., 2022 study has a common result with this experiment's result. In Masataka and Grandgeorge's (2016) study, it was found that blue, brown, and green were the most selected, and pink was the least selected color in ages four to seven. There are some similarities between Masataka and Grangeorge's (2016) study with this experiment. In this experiment, the yellow color of light increased positive behaviors (playfulness and eye contact), similar to their study. However, in the Nair et al., 2022 study, yellow and white were considered negative colors. In this study, white triggered negative behavior (refusal of task), which has a similar outcome to Nair et al.'s study in terms of the color of white.

### Limitations

This study has potential limitations. Firstly, this study had to be conducted during the duration of the scholarship of the Scientific and Technological Research Council of Türkiye (TÜBİTAK), which was given during the COVID-19. Therefore, the participants to study were limited.

Secondly, colors were tested sequentially, which can be used as preliminary data. However, a random order of color test application needed to be made. In this way, later colors may not be influenced by prior color exposure. Moreover, this study is exploratory. Therefore, confirmation of the result can be made with larger sample sizes, randomized color sequence, and more inferential statistics.

### Conclusion

This research aimed to fill the gap in the literature by asking two main research questions: Do participants' behavior change significantly depending on the chosen colors of light? Which colors of light trigger positive and negative behaviors? Depending on the research questions and aim, it has been noticed that there is a link between the color of light and the behavior of children on the spectrum. According to the behavioral observation of 13 children on the spectrum, it was found that some colors of light trigger positive behaviors and negative behaviors.

Depending on the observation, playfulness (84,6%) and eye contact (7,7%) were primarily observed in yellow. Refusal of the task was seen most in white (38,5%). Repetitive body movement was mostly observed in yellow (7,7%) and red light (7,7%). The repetitive speech was primarily seen in red (7,7%) and blue (7,7%). Aggression was seen mostly in white (Table 16). The relationship between the behavior of children on the spectrum and the color of light was an uncovered topic. Therefore, in this study, it was perceived that the yellow color of light triggered positive behaviors such as playfulness and eye contact. On the other hand, red and white colors of light triggered negative behaviors, such as refusal of task, repetitive speech, repetitive body movement, and aggression. Thanks to this knowledge, lighting design can be applied according to the features of triggering positive and negative behaviors for children on ASC in the educational and needed areas.

### Data availability

The dataset was generated by behavioral observation. During the analysis of the observation, cross table was prepared to perceive the relation between behavior and color. The quantitative result was achieved by the software of IBM SPSS 26. All data set can be reached via <https://doi.org/10.6084/m9.figshare.29958968> (<https://figshare.com/s/984fa756d1ebd92c71e6>).

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## Author contributions

The first author conducted all the research, analyzed, and wrote the whole manuscript. The second and third authors shared feedback in the process and checked the manuscript.

## Competing interests

The authors declare no competing interests.

## Ethical approval

This study was performed in line with the principles of the Declaration of Helsinki. It is ethically approved by 35853172-663.08 number by Hacettepe University's Ethics Committee on 21.04.2020. The scope of approval includes designing educational environments to support physical and psychological wellbeing of children on Autism spectrum disorder who are between the ages of 5 to 11. The research was done between the dates of 01.02.2021 to 31.07.2021. It was funded by TÜBİTAK (Turkish Scientific and Technological Research Council) with 53325897- 115.02-24993 Grant Number.

## Informed consent

In this study, written informed consent was taken from the parents or accompanies of children on the spectrum. Informed consent was taken between the dates of 25.01.2021 to 29.01.2021. Informed consent covers study purpose, inclusion/exclusion criteria, participation procedures and duration, data anonymity, risks and discomfort, benefits, and voluntary participation sections. All participants have been fully informed about the research, and the participants' anonymity is assured.

## Additional information

**Supplementary information** The online version contains supplementary material available at <https://doi.org/10.1057/s41599-025-05820-w>.

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