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MASTER THESIS

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DEVELOPMENT OF FOVEAL AND PERIPHERAL SELECTION IN PRE-ADOLESCENTS (7-14 YEARS OLD)

Lawrence Stolk 3783863

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Supervisor & First Reviewer: Roy Hessels

Second Reviewer: Ignace Hooge

Development of foveal and peripheral selection if pre-adolescents (7-14 years old)

Lawrence C. Stolk

Utrecht University

Abstract

A lot of the current literature about visual search for individuals is focused on either children with Autism Spectrum Disorder (ASD) or adults. There are no studies focusing the underlying processes of visual search by children with typical development. In this study, we conducted an eye-tracking task on pre-adolescents (age 7-14) to measure how foveal processing and peripheral information selection develops over age. Participants had to find a target among distractors with similar features and less similar features. When the spatial frequency and the orientation of the elements were more similar to the target, an increase in processing time was reported. Moreover, a negative relation indicated that the processing time of these elements decreases between the age of seven and fourteen. Furthermore, participants used the spatial frequency as well as the orientation of elements for selection of the next element to process. At last, no relation was found between the use of spatial frequency and orientation for selection of the next target and the age of seven to fourteen.

Keywords: visual search, foveal selection, foveal processing, peripheral selection, eye tracking

Imagine yourself standing in a huge parking lot with 1000 cars, and you are searching for your black VW Golf, one of the most common cars on the parking lot. To find your car, you will probably need to look at most of the black cars, while you try to ignore the coloured cars. You focus on a black car, somewhere in the area where you thought you left the car and tried to determine if this is a black VW golf. When you see it is a black VW Golf, you will probably check the number plate to see if it is your car. You decide that the current car you are looking at is not your car. The next step would be to check the next black car. Instead of focusing on all the cars one by one, you can select the next black car from the periphery of your vision. However, the low resolution in the periphery does not provide enough details to differentiate between two almost identical black cars. Luckily you can still differentiate between a bright blob and a dark blob. With this information, you can distinguish the cars which look like your car and the cars which are completely different. This will improve the efficiency of your car search.

Selecting objects from the periphery of your vision and deciding if one of these is the object you need is very common behaviour during the human lifespan. For example, babies look around to select their parents' faces from a crowd; young children try to find their favourite game on a website while distracted by advertisements (Holmberg, Holmqvist, & Sandberg, 2015). Adolescents try to find their friends at a schoolyard and adults look for black cars in a parking lot. Two different processes can characterise visual search behaviour. The first process is to focus on an object and process if it is the target you are looking for (i.e. foveal selection). The second process is to decide what to focus on next if the current item is not the intended target (i.e. peripheral selection) (Hooge & Erkelens, 1999; Keehn & Joseph, 2016). Although this behaviour is very common during the lifespan, it is not clear yet how foveal and peripheral selection develops over time. Do children get better at discriminating information in the foveal area or do they become better at selecting the next target.?

The literature on visual search behaviour describes the development of visual search as a U-shape (Plude, Enns, & Brodeur, 1994). During childhood and early adulthood, humans tend to become better and faster at cognitive tasks (Belmont, 1996), e.g. selecting objects from a crowded screen (Wolfe, 1994). Later on, this behaviour starts to fall off, and humans take more time to select the right target, and the number of mistakes they make increases (Hommel, Li, & Li, 2004; Scialfa, Esau, & Joffe, 1998). Furthermore, Trick and Enns (1998) found that young children and seniors were less able than young adults to adjust their visual attention to a target while being distracted. In the last 20 years, much research has been conducted on the development of visual search behaviour (Carrasco, 2011). The available evidence seemed to be mainly focused on visual attention, conjunction & feature search or groups with atypical development such as children with Autism Spectrum Disorder (ASD) (Brenner, Turner, & Müller, 2007; O'riordan, 2004; Wolfe, 1994; Wolfe & Pashler, 1998). For example, Kaldy, Kraper, Carter and Blaser (2011) reported that children with ASD searched more effectively than children with typical development. O'Riordan, Plaisted, Driver and Baron-Cohen (2001) found that children with ASD were also quicker and more accurate than their peers in finding the right target in single feature search and conjunctive search. Furthermore, Baldassi et al., (2009) reported that children with ASD had a lower relative discrimination threshold than the typical development control group. Hommel et al., (2004) noticed that there are relatively few studies investigating visual search behaviour during child development. Most of the research is done on adults, and when it is focused on development, as mentioned above, it tends to focus on atypical development (Gliga, Bedford, Charman, Johnson, & BASIS Team, 2015; Kaldy, Giserman, Carter, & Blaser, 2013). Hessels, Hooge, Snijders and Kemner (2014) discuss the fact that some studies find a difference between individuals with ASD and the controls, but that there are also studies where this difference is not found (Constable, Solomon, Gaigg, & Bowler, 2010). It seems that a lot of the current literature about visual search for individuals with ASD is focused on faster search or accuracy (Kaldy et al., 2013) but there are no studies focusing the underlying processes of visual search by children with typical development. Joseph & Keehn (2016) investigated how advantages in foveal selection and peripheral selection might contribute to superior search performance in ASD, but there is still a lack of knowledge concerning the typical development of foveal selection and peripheral selection.

Burggraaf, van der Geest, Frens & Hooge (2016) tried to answer this gap in the literature by conducting a study on the development of foveal selection and peripheral selection in adolescents (ages 12-19). Their study consisted of an eye-tracking experiment at a high school in The Netherlands, in which a total of 128 high school students participated. The experiment consisted of 144 trials, and each trial contained a search screen. A search screen was made of 36 Gabor patches. Gabor patches are circular patches of alternating light and dark vertical bars (Weil et al., 2013). These elements were chosen because there is much research done on Gabor patches and the properties, like spatial frequency and rotation are easily manipulated (Polat & Tyler, 1999). Participants were asked to sit in front of a computer and complete all the trials. During each trial, they were asked to decide whether it contained a target present screen or a target absent screen. The target was a Gabor patch of 17 cycles per visual degree, with vertical bars and surrounding the target were 35 distractors. There were two types of distractors, 72 trials contained 36 high-frequency (HF) elements with 17 cycles per visual degree elements. The other 72 trials had 17 or 18 HF elements, depending if the trial contained a target present or target absent screen, and 18 low-frequency (LF) elements with ten cycles per visual degree. The distractor elements were tilted 10, 30, 50, 70 or 90 degrees clockwise or counter clockwise. This study showed that adolescents become better in foveal selection because the processing time per element was decreased over age, meaning that older students needed less time per element to decide whether it looked similar to a target or not. Furthermore, the data showed that students had a lower number of fixations on the LF elements. This data suggests that adolescents already select the next HF elements over LF elements. However, this did not correlate with age, so it appears that the selection of information from the periphery does not change during adolescence.

This study tries to answer the question of how foveal selection and peripheral selection develops during the pre-adolescence (7-14). To accomplish this goal, a shorter version of the eye tracking experiment of Burggraaf et al., (2016) was conducted with the 82 students from the Netherlands. Half of the students were recruited at a primary school, while the other half was recruited at a cultural event in Utrecht. Due to the lower age of the participants, there was a likelihood that they had difficulties with concentrating for the complete experiment. Therefore, the total amount of search screens was lowered from 144 to eighteen. The children were asked to perform the same search screens with 36 elements per screen. Nine screens contained a target and nine did not. This study examined if the average time a participant was fixating on an element changed between seven and fourteen to get a better understanding how foveal selection develops between 7 and 14. Secondly, this study investigated if the number of fixations on the different types of elements changed between 7 and 14. This was done to get a better understanding which information children use from the periphery to select the next element for further processing.

Method

Participants

A total of 81 (47 male, 34 female) preadolescents participated in this study. Out of these 81 participants, 52 (29 male and 23 female) were recruited from class 4 to 8 at a primary school in Amersfoort. The other preadolescents were recruited at a cultural event in the city centre of Utrecht. Five children were excluded because their informed consents and demographics questionnaire forms were either inconsistent or incomplete, i.e. the date of birth was different on the informed consent than on the demographic questionnaire. Another two were excluded because one of their close relatives were diagnosed with ASD, one participant was excluded because the participant forgot to wear glasses, and did not have normal or corrected to normal vision. A-prime was computed to check if the participants were able to do the task and if they understood the task. A-prime is a measure of sensitivity from signal detection theory (Stanislaw & Todorov, 1999), a-prime is calculated from the proportion hits and misses of detecting the target. Scores range between 0 and 1, where 1 is a perfect score, and .5 implies performance at chance level. A cutoff score of .6 was selected because this implies a participant scored better than chance. Making it safe to presume that the participants understood the task and were able to execute it properly. If the A-prime fell below .6, it was possible that participants had guessed or did not understand the task. Two participants were excluded because their a-prime was below the .6 threshold. The combined age of all the participants (N = 71) who were included ranged from 7.58 to 13.70 (M = 10.33 and SD = 1.42).

Participation in the experiment was voluntary. Children at the primary school received an envelope with an information letter, a demographic questionnaire, and an informed consent form. They were asked to return these forms, signed by their parents and themselves (if they were over the age of 12), to their teacher. At the cultural event, there was a stand where children and their parents could line up. If they wanted to participate, they were informed about the study and asked to sign an informed consent and fill in a demographic questionnaire. The study was approved by the ethics committee of the Faculty of Social Science at the University of Utrecht.

Apparatus

The trials with search screens were presented on a 23” screen with a resolution of 1920 by 1080 pixels and 60hz refresh rate. The screen was attached to a Tobii TX300 Eye Tracker running at 300 Hz. The TX300 is capable of recording, under ideal conditions, at 0.4^0 accuracy (binocular) and 0.14^0 precision. The experiment was run on a MacBook Pro with OS X 10.9, using Matlab 2013a and PsychToolbox 3.0.11 (Brainard, 1997). The Tobii SDK was used to communicate between the MacBook and the Tobii TX300. Furthermore, this study used a Design Organization Test (DOT) designed by Killgore, Glahn and Casasanto (2005) to measure the visuospatial ability of the participants. The DOT task was validated for adolescents between 12 and 18 by Burggraaf, Frens, Hooge & van der Geest (2015). For the statistical analyses, IBM SPSS Statistics 20 and MatLab R2015b were used.

Stimuli

The search displays were shown in a resolution of 1240 by 1024 pixels, centered in a 1920 by 1080 screen. Each search screen contained 36 elements. These elements were divided over six rows of six elements. Each element consisted of a Gabor patch, 18 with ten cycles per visual degree and 18 with 17 cycles per visual degree. Their orientations varied at random between 10°, 30°, 50°, 70° and 90° clockwise and counterclockwise. As explained before, half of the trials contained a target; the target was a high-frequency patch with a vertical orientation. Only the patches with 17 cycles per visual degree could be a target; low-frequency elements were never in a vertical position.

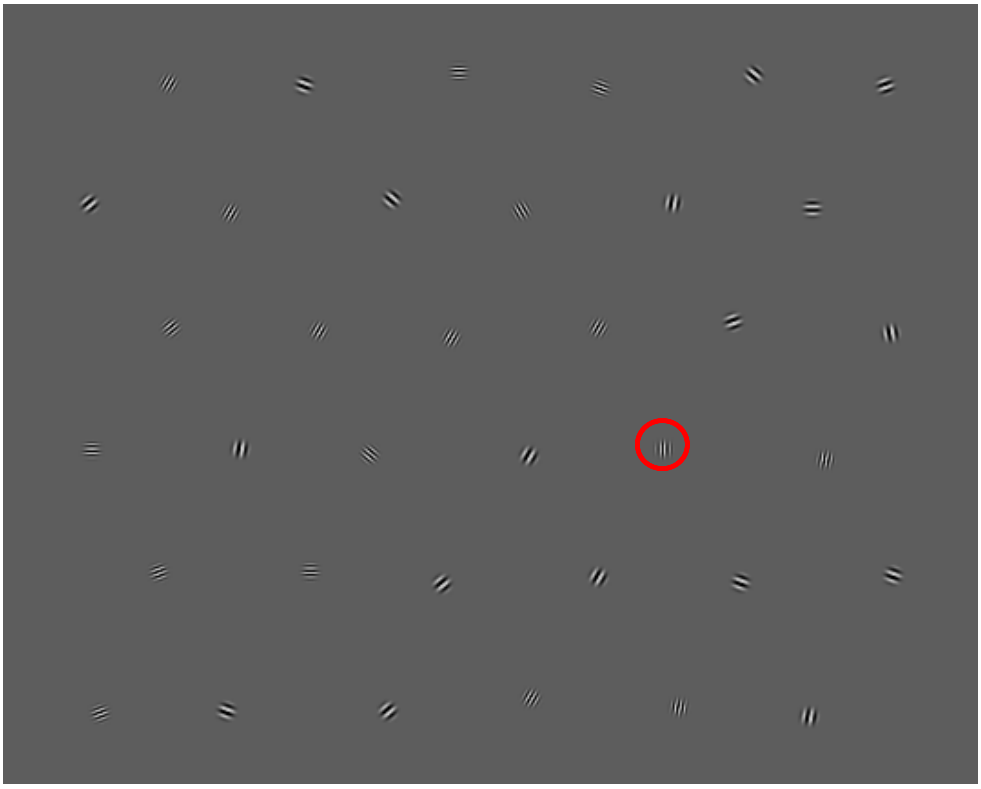

Figure 1. Example of a target present search screen with 18 HF and 18 LF elements

Procedure

General Procedure. The children were welcomed to the experiment and seated in the adjustable office chair. During the cultural event, the experiment was conducted in a small tent, used by Hessels, Anderson, Hooge, Nyström and Kemner (2015) for eye-tracking experiments with babies, to shut out the sunlight and keep consistent lighting per participant. At the primary school, the blinds of the room were adjusted to create consistent lighting.

The experiment consisted of four steps. First, participants were given an explanation about the procedure and as a part of this, the participants were given two sample search screens on paper, to get them used to the task. The next step was the calibration of the Eye Tracker. During this step, the participants were told they had to watch anything that happened on the screen as well as possible, while the experimenter checked whether the calibration succeeded. The children were not made aware that they were part of a calibration test, to allow the experimenter to recalibrate without giving the children the feeling that they failed. The third step were the eighteen search screens, and the last step was the DOT task.

Calibration. The second step of the experiment was a 5-point calibration procedure of the Eye Tracker. The calibration stimuli consisted of a coloured spiral (red, green, yellow, purple, or blue) on a black background. The spiral changed in size between 4.0° and 5.4° at 0.8 Hz following a sinusoidal wave. In addition, the spiral rotated at 0.8 Hz. Following a key press of the operator, the spiral shrank in size to 0.5° over a period of 0.5 sec. The spiral changed in size between 4.0° and 5.4° at 0.8 Hz following a sinusoidal wave. In addition, the spiral rotated at 0.8 Hz. Following a key press of the operator, the spiral shrank in size to 0.5° over a period of 0.5 sec.(Hessels et al., 2015). During each point, there was a pulsing sound in the background. When the experimenter thought the participants looked in the direction of the calibration points, he pressed the spacebar. Because the Tobii Pro Analytics SDK does not have an objective way of measuring accuracy[1], the experimenter judged if the calibration points were with or without data, if the gaze points were consistent and if there was no dispersion around the calibration point. When the calibration data did not fulfil those specifications, the experimenter decided to rerun either all the calibration points or just the calibration points which failed to deliver the right data. If the calibration data did meet the specifications, the children were told that the next step was about to start and, the children were given a quick question to make sure that they still knew what to do.

Visual search task. The experiment consisted of 18 trials; each trial started with a grey screen containing a white fixation cross. The participants were told that if they pressed the spacebar, the task would start and they would see the first search screen. They were asked to examine each search screen for a target. When they found a target they had to press the arrow up key and the fixation cross would appear on the screen again, this was the end of the

[1] http://www.tobiipro.com/product-listing/tobii-pro-analytics-sdk/

trial. If the participants pressed the spacebar again, the next trial would start. If the search screen did not contain a target, they were asked to press the arrow down key, and the next trial would start as well. When a participant spent more than 30 seconds on a search screen, the trial would finish automatically; this was counted as a miss, and the next trial would start. These steps were repeated until the participants finished the 18 trials. The procedure took 5 to 10 minutes including explanation and calibration. Afterwards, the participants went to another room to complete the DOT task.

Design Orientation Test. The DOT consists of three forms; the first one was an example form, and the next two forms were the actual test. For the DOT participants have to match a pattern with a number key.

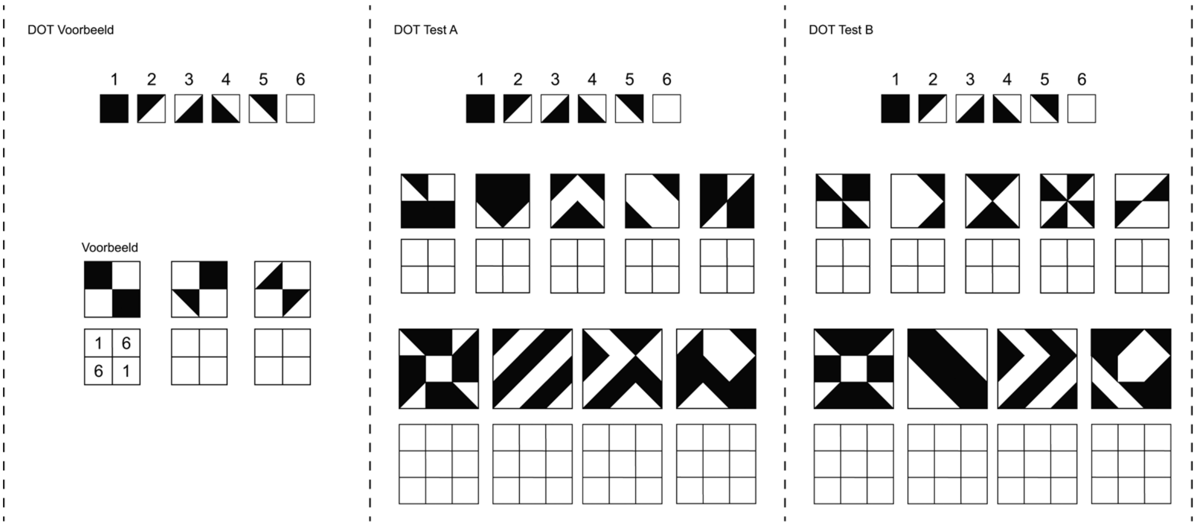

Figure 2 The three forms of the Design Orientation Test (DOT). "Voorbeeld means example in Dutch."

As shown in figure 2, at the top of each form participants can see which number matches which each pattern. The goal of each form is to fill in as many numbers as possible in one minute. First, the participants were given the example form of the DOT task, with four two-by-two grids. The first grid was already completely and the second grid has two filled squares. The participants were given as long as they needed to practice. After they had finished the practice rounds, the experimenter asked if the participant understood what they had to do and checked the response to be sure they did. The actual DOT they were given consisted of the “A” and “B” form. These forms consisted of five two-by-two grids and four three-by-three grids. They had one minute to fill as many numbers as possible, and they did not need to follow a certain order. Instead, the participants could fill any square they wanted, for example, they could fill two squares of the first grid and three in the last grid. The experimenter started the timer when the participant filled in the first square, and after one minute the participant was asked to stop. If they were done with form “A” the experimenter turned the page to sheet “B” and then the participant could start again. The DOT took 5 minutes including explanation and the actual test.

Results

Only target absent trials were used for the statistical tests. The use of target present screens in the statistical analysis could lead to an artificial lowering of the mean dwell time and the average amount of dwells on elements. Whenever there was a target present, there was a possibility that the participants spotted the target very quickly and did not check the other stimuli.

Foveal Selection

As a measure for foveal selection, the average dwell time per element was calculated. The average dwell time was calculated by adding the duration of the individual fixations on a specific element divided by the number of fixations (see formula 1).

$$Average\ dwell\ time = \frac{\sum Duration\ of\ individual\ fixations\ on\ \ a\ element}{number\ of\ fixations\ on\ a\ element} \qquad (1)$$

The average dwell time was used as a measure of the processing time of an element. A two by five repeated measure analysis of variance (ANOVA) was conducted to check if there was a change in processing time of the participants. As within-subject factors, Frequency (i.e.

10°/cycle or 17°/cycle) and Orientation (90°, 70°, 50°,30° and 10°) were used. The average amount of dwell time per element was used as the dependent variable.

Mauchly's test indicated that the assumption of sphericity was violated for the orientation effect, $\chi^2(9) = 56.149$, $p = <.001$ and for the interaction effect between frequency and orientation $\chi^2(9) = 53.156$, $p < .001$. Therefore the degrees of freedom were adjusted according to the Greenhouse-Geisser estimates of sphericity with $\varepsilon = .691$ for the orientation and $\varepsilon = .717$ for the interaction effect. The test was one-sided, and an alpha of .01 was chosen because earlier research showed robust differences in these search tasks (Burggraaf et al., 2016). A main effect was found for orientation, $F(2.764, 193.464) = 52.075$, $p = < .001$. As figure 3 shows, participants needed significantly more time to process the elements which were very similar to the target element. A main effect for Frequency was revealed, $F(1,70) = 263.909$, $p = <.001$.

This data suggests that participants needed longer processing times if they were looking at a HF elements, compared to the LF elements. A significant interaction effect was found with F (2.869, 200,828) = 68.780, $p = <.001$, this shows that the participants only selected on orientation when they were looking at a HF element.

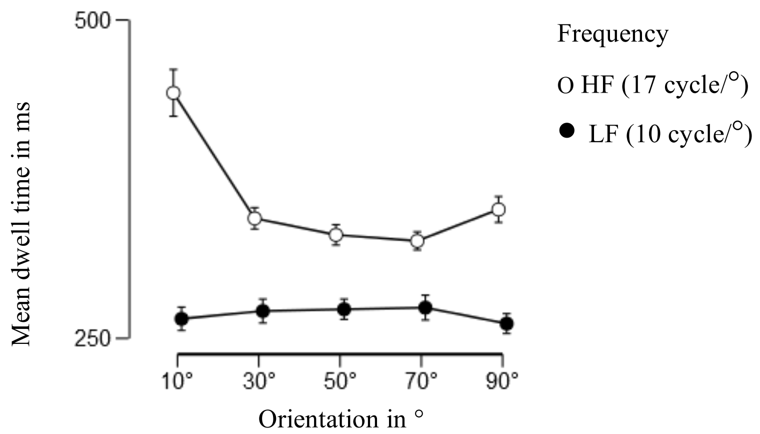

Figure 3. Mean dwell time in ms per HF and LF element

Multiple pairwise comparisons (Bonferroni adjusted) were conducted for the interaction effect. These showed that there was a significant difference between HF 10° elements and HF 90°, 70°, 50° and 30° elements (all p = <.001). Furthermore there was a significant difference between HF 90° elements and HF 70° elements(p = < .001). This result suggests that the participants were slower in discerning the difference between elements looking close to the target (10°). For the low frequency (10°/cycle) elements, there was no significant mean difference.

Foveal selection over age

Correlation with age. Correlation coefficients were calculated between average dwell time and age. This was done to see if there was a change over time. Significant correlations were found for various rotated high-frequency elements with age, see table 1. This suggests that over time participants needed less processing time per element. An alpha of .05 was used because this study has a small amount of trials which could result in skewed mean estimates.

Table 1

Correlation between HF elements and age

Element type	Pearson Correlation(r)	p (1-tailed, α = .005)
High frequency 10°	-.365	<.001
High frequency 30°	-.355	<.001
High frequency 50°	-.361	<.001
High frequency 70°	-.396	<.001
High frequency 90°	-.378	<.001

For the low frequency elements there was a significant negative correlation for 90° where r = -.345, p = .003, 50°, r = -.415, p = <.001 and 30° r = -.369 and p = .002. The 70°

and 10° elements had no significant correlation with age. This suggest that the participants became faster in deciding if an element was the target or not over age regardless of the spatial frequency of elements.

Correlation with DOT. The DOT score is a measure for visuospatial intelligence, and correlation coefficients were used to determine if lowering of dwell time correlated with the visuospatial development. The DOT score was calculated by deducting the incorrect answers on both forms from the number of answers given on both forms and then divided by 2 (see formula 2).

$$Dot\ score = \frac{((\text{number of answers A} + \text{number of answers B}) - (\text{number incorrect A} + \text{number incorrect B}))}{2} \quad (2)$$

Only the 90°, 70° HF elements and 30° LF elements correlated with the DOT score (all p = > .005). This suggests that there is no correlation between visuospatial development and the change in processing time.

Peripheral selection

As a measure for peripheral selection, the average amount of dwells was calculated.
The average amount of dwells was calculated by taking the total amount of the individual fixations on a specific element type and dividing these fixations by the number of times this the specific element is present in the experiment (see formula 3).

$$Avg.amount\ of\ dwells\ = \frac{\sum individual\ fixations\ on\ a\ specific\ element\ type}{number\ of\ times\ this\ element\ is\ present\ in\ experiment} \quad (3)$$

A two by five repeated measure analysis of variance (ANOVA) with Frequency(i.e. 10 cycle/° or 17 cycle/°) and Orientation (90°, 70°, 50°,30° and 10°) as within-subjects factors was conducted. With the average amount of dwells per element (see formula) as the dependent variable. This ANOVA was to determine which information the participants used from the periphery to select the next element for further foveal processing.

Mauchly's test indicated that the assumption of sphericity was violated for the orientation effect, $\chi^2(9) = 29.259$, $p = <.001$ and for the interaction effect between frequency and orientation $\chi^2(9) = 25.638$, $p = .002$. Therefore the degrees of freedom were adjusted according to the Greenhouse-Geisser estimates of sphericity with $\varepsilon = .823$ for the orientation and $\varepsilon = .828$ for the interaction effect.

A main effect was found for Orientation, $F(3.293, 230.523) = 29.997$, $p = < .001$, which suggests that the participants were able to select the next element, depending on the different orientations of the elements in the periphery. A main effect for Frequency was revealed, $F(1,70) = 257.879$, $p = <.001$. This suggests that participants selected the HF elements more often from their periphery than the LF elements for further processing. An interaction effect was found significant with $F(3.312, 231.874) = 25.806$, $p = <.001$. This provides evidence that the participants only selected on the orientation of an element when the object was a HF element.

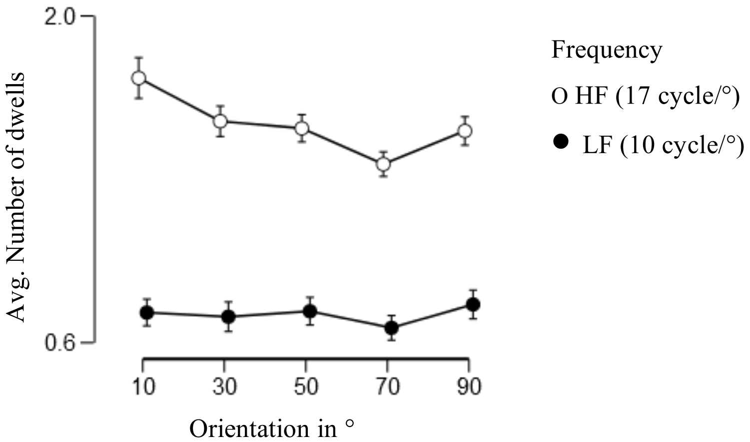

Figure 4. Average number of dwells per element type

Multiple pairwise comparisons (Bonferroni adjusted) were conducted. As figure 4 shows there were significant differences between the HF 10° elements and the others (all $p = < .001$) and the same for the HF 70° elements (all $p = < .001$). This indicates that participants selected the HF 10° elements more often from the periphery than the other orientated HF elements. Furthermore, it indicates that participants selected the HF 70° less than the other orientations.

Correlation with age. Correlation coefficients were calculated between the average amount of dwells and age. This was done to measure a change in the information pre-adolescents used when they got older. The data did not indicate a correlation (all $p > .005$) between age and the average number of dwells per element. This data suggest there is no change in information selection from the periphery over age.

Correlation with DOT score. Correlation coefficients were calculated between the average amount of dwells and DOT score (see formula 3). The data did not indicate a correlation (all $p > .005$) between age and the average number of dwells per element. This data suggest that development of the visuospatial abilities has no influence on the selection from the periphery.

Discussion

This study investigated the development of foveal selection and peripheral selection on frequency and orientation of elements in pre-adolescences. The results of the experiment were in accordance with earlier research from Burggraaf et al. (2016). The findings indicated that while searching for a target, the participants need more processing time for elements which are very similar to the target opposed to elements which are obviously not related to the target. To be precise, if the spatial frequency and the orientation of the elements were more similar to the target than the processing time increased. Furthermore, a negative relation was found between the processing time of the frequency and the orientation of elements and age. This relation indicated that the processing time of these elements decreases between the age of 7 and 14.

The results for the peripheral selection were also in accordance with Burggraaf et al. (2016). Participants used the spatial frequency as well as the orientation of elements from their periphery for selection of the next element to process. Elements more similar to the target were more often selected than the elements with different spatial frequency or different orientation less similar to the target. No relation was found between peripheral information selection and the age of the participants; this indicated that the selection of spatial frequency and orientation from the periphery does not change between seven and fourteen years old.

The participants conducted a task to measure their visuospatial development; no relation was found between the visuospatial development of 7 to 14-year-olds and the processing time of the spatial frequency and the orientation of the elements. Neither was there a relation between the visuospatial development of 7 to 14-year-olds and the peripheral selection of spatial frequency or orientation. The absence of a relation between foveal selection can be explained; The visuospatial abilities measured did not include processing time of the stimuli but seemed to be focussed on the spatial properties only. An explanation could be that the development of foveal selection deviates from the visuospatial development. Furthermore, there is no relation between visuospatial development and peripheral selection; this lends support to the evidence that there is no change in the selection of spatial frequency and orientation from the periphery between 7 and 14. A limitation to the visuospatial task, which was conducted during the experiment, was the absences of verification for pre – adolescents. The task was verified for children between 12 and 19 and it is possible that the task was too complicated for the participants.

There are some other limitations of the present study to consider. First, the conditions between the two different participant groups were, despite the precautions, not completely similar and this could have had an effect on the raw data of the eye-tracker. The room was different, and there were different operators. According to Nyström, Andersson, Kenneth and van de Weijer (2013) the operators can have a significant impact on the data. Secondly, there are no other studies on this particular subject, and it is possible that the younger children (7-10) could not keep their concentration during the entire experiment.

A possible explanation for the change in processing time over age could be the oculomotor development. Aring, Grönlund, Hellström and Ygge (2007) showed that the density of fixations around the centre of gravity increased between 4 and 15 years. It could be possible that the younger participants were not able to keep their fixation stable enough on the elements and therefore could not process the element as well and needed more processing time. This could be verified by calculating the amount of dwells next to elements instead of on the elements. If the oculomotor muscles are not fully developed, then there will be more dwells next to the elements because the children are not able to keep their fixations completely steady. The older children have more control over their oculomotor muscles and can fixate more steadily on the elements.

This study tried to describe the typical development of foveal selection and peripheral selection. The information gained from this study can be used as a baseline for further research into the typical and atypical development of visual search behaviour.

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