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Eye Tracking as an Objective Measure of Hyperphagia in Children with Prader-Willi Syndrome

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Abstract

This study examined sensitivity of eye tracking measures to hyperphagia severity in Prader-Willi syndrome (PWS). Gaze data were collected in 57 children with PWS, age 3–11 years, and 47 typically developing peers at two study sites during free visual exploration of complex stimulus arrays that included images of food, animals, and household objects. Analysis of the number and duration of fixations as well as gaze perseverations revealed that food items are not exceptionally salient for children with PWS. Instead, increased attention to food in the context of other high-interest items (e.g., animals) was associated with caregiver reports of more severe hyperphagia and more advanced nutritional phase. The study also provided preliminary evidence of possible genetic subtype and sex differences as well as demonstrated that multiple investigators in a wide range of settings can effectively implement the eye tracking protocol. The results indicate that gaze characteristics derived from eye tracking may be a promising objective marker of hyperphagia in PWS for use in research and clinical trials.

Keywords

Prader-Willi syndrome; hyperphagia; eye tracking; nutritional phase

Prader-Willi syndrome (PWS) is a genetic disorder caused by abnormalities on the chromosome 15q11–13 due to a paternal deletion (70% of cases) or duplication of the maternal chromosome (maternal uniparental disomy, mUPD; 25% of cases) (Butler, 1990; Nicholls, Knoll, Butler, Karam, & Lalande, 1989). One distinctive feature of the PWS phenotype is hyperphagia, or intense hunger and overeating (Dykens & Cassidy, 1999;

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Author Contribution

Alexandra Key: designed the study, participated in data collection, carried out statistical analyses, wrote, reviewed and revised all drafts the manuscript and approved the final manuscript as submitted.

Anastasia Dimitropoulos: contributed to study design and interpretation, reviewed and revised all drafts of the manuscript and approved the final manuscript as submitted.

Hatun Zengin-Bolatkale : programmed the final version of the experimental protocol, participated in data collection, carried out preliminary analyses, contributed to data interpretation, reviewed and revised all drafts of the manuscript and approved the final manuscript as submitted.

Ellen Doernberg: participated in data collection, contributed to preliminary analyses, reviewed and revised all drafts of the manuscript and approved the final manuscript as submitted.

Milner et al., 2005). Hyperphagia emerges in early childhood (starting around age 3, Miller et al., 2011) and remains a life-long concern for persons with PWS and their caregivers (Hodapp et al., 1997). Yet, it is challenging to objectively evaluate hyperphagia. Persons with PWS tend to demonstrate socially desirable behaviors in a laboratory compared to community settings, reducing the effectiveness of direct behavioral observations of food consumption (Holland et al., 1995; Tan et al., 2004; Zarcone et al., 2004) or self-reports (Dykens, 2000). Currently, the main source of data regarding hyperphagia in PWS is informant questionnaires (Russell & Oliver, 2003; Dykens et al., 2007). While specifically targeting hyperphagia symptoms in PWS, they nevertheless are an indirect measure and subject to potential respondent bias.

Recent advancements in the development of noninvasive and low-cost measures of physiological processes, such as eye tracking, offer a novel possibility to directly evaluate food-related interest in persons with PWS. Research has shown that more salient stimuli in the visual field attract a greater number and longer duration of eye gaze fixations (Colombo et al., 1995; Sasson et al., 2007, 2008). Eye movements are a natural human behavior that does not need to be taught, and without the need for an overt verbal or behavioral response, eye tracking measures circumvent many confounds related to task understanding or social desirability, and can be used across ages and levels of adaptive functioning (e.g., Venker & Kover, 2015; Chita-Tegmark et al., 2015).

Food-related eye tracking studies in non-PWS populations have demonstrated that gaze patterns vary with satiety and voluntary food behaviors. Typical healthy-weight adults exhibited increased gaze to food in the fasting vs. fed condition (Castellanos et al., 2009; Giel et al., 2011). Conversely, voluntary food avoidance in patients with anorexia nervosa was associated with reduced visual attention bias for food vs. control images (Giel et al., 2011). Those studies used paired picture presentations contrasting single food and nonfood items. Such designs allowed to examine visual attention to particular individual items, but also provided highly simplified environment for examining general salience of different stimulus categories or the role of stimulus context.

A visual exploration paradigm, where multiple exemplars from the contrasting categories (e.g., high and low salience images) are present at the same time (e.g., Sasson et al., 2008), offers additional insights about the relative interest in one type of stimulus over another as well as about information processing in general, such as the extent of visual exploration (number of different items looked at) and perseveration (repeated gaze at the same item). Recently, Key and Dykens (2018) demonstrated that in children and adults with PWS (6–35 years, M age =15), increased number of gaze fixations and perseverations on food was associated with higher total scores on the Hyperphagia questionnaire (r=.35−.65 depending on the amount of available gaze data). Of note, those associations were observed only for the trials where food items were presented along with animals, a competing stimulus category expected to be highly salient for persons with PWS due to their strong nurturance interest (i.e., desire to be with and care for animals and babies; Dykens, 2006).

In the current study, we aimed to examine sensitivity of the visual exploration paradigm to hyperphagia in younger children with PWS during the developmental period when hyperphagia emerges (3–11 years). Given that hyperphagia onset spans a wide age range and presents gradually instead of as an abrupt shift in eating behavior (Miller et al., 2011), examining gaze patterns in response to food across the development of hyperphagia will allow us to determine if the eye-tracking paradigm is sensitive to variance in hyperphagia, as many younger children have not reached nutritional phase 3 (full hyperphagia). In addition, as this task has not been previously administered in preschool age children, we will evaluate the feasibility of the paradigm in children as young as three years of age. We hypothesized that in the context of increasing food interest, eye tracking data will differentiate children with PWS from age-matched typical children and will vary according to the individual's nutritional phase (assessed by a clinician) and hyperphagia severity (caregiver report). To increase our sample size and to evaluate feasibility of implementing eye tracking in a broader PWS research community, we collected data at two sites: Vanderbilt University Medical Center and Case Western Reserve University.

Method

Editorial Policies and Ethical Considerations

The study was conducted with approval from the local Institutional Review Boards (Vanderbilt University Medical Center and Case Western Reserve University). Parents/guardians of all participants provided written informed consent, and all children indicated their assent for all study procedures.

Participants

A total of 57 children with PWS aged 3 to 11 years (M = 6.32, SD = 2.54 years; 22 males) and 47 typically developing children (M age = 7.35, SD = 3.01 years; 23 males) participated in the study across two sites (see Table 1 for participant characteristics). The two groups were not significantly different in age or body mass index (BMI), but the PWS group had lower mean composite IQ compared to the typical group (74.55 vs. 112.81, $p<.001$) as assessed using Kaufman Brief Intelligence Test-2 (K-BIT-2; Kaufman & Kaufman 2004). The PWS diagnosis was confirmed using genetic testing reports provided by each participant's family. Thirty-four individuals with PWS (M age = 6.91, SD = 2.60; 15 male) had the deletion subtype of PWS, and 18 had the maternal UPD subtype (M age = 5.28, SD = 2.37; 6 male). Two additional participants had PWS due to imprinting center mutation. Genetic subtype was not included in the reports for 3 participants. The deletion and mUPD subgroups did not differ in IQ, BMI, or hyperphagia severity. However, the deletion subgroup was significantly older (6.91 vs. 5.28 years) and at a more advanced nutritional phase than the mUPD subgroup. All participants had normal or corrected-to-normal vision. Consistency in data acquisition procedures was ensured by joint in-person training on study procedures for the research staff at both sites.

Hyperphagia Evaluation

Parents of all participants completed the 9-item Hyperphagia Questionnaire-Clinical Trials (HQCT; Dykens et al., 2007), which uses a 5-point Likert-type scale (score range: 0–4) to evaluate hyperphagic behaviors, drive, and severity (e.g., persistence in food seeking, emotional reactions to food restriction). The HQCT total score is a sum of all responses (score range: 0–36), with higher scores indexing more severe hyperphagia. Parents based their responses on behaviors demonstrated across different environmental settings (e.g., home, school, community) during two weeks preceding the assessment. As expected, children with PWS had a significantly higher HQCT score than the typical group ($p<.001$; see Table 1).

Additionally, parents in the PWS group completed an interview with a clinician experienced with PWS to determine the nutritional phase for their children (Miller et al., 2011). The Nutritional Phases survey contains 45 items grouped into categories (score range: 0–4) ranging from failure to thrive to full hyperphagia or hyperphagia resolution. A nutritional phase was considered “met” when most of the endorsed items fell within that phase as determined by clinical judgment.

Visual Exploration Task (Key & Dykens, 2018)

Stimuli.—Color images representing common foods (high and low calorie options), animals (in non-aggressive poses), and household objects (e.g., furniture, clothes, small appliances) served as the stimuli. All individual images occupied comparable physical space. The 72 possible images (3 categories × 24 exemplars) were grouped into 12 arrays presented on colored background (yellow, pink, green, blue), each consisting of 24 images representing two categories (e.g., food+animals, food+objects, animals+objects; see example in Figure 1). The number of images from each category within an array varied from 4 (17%) to 12 (50%) to 20 (83%). The four background colors were used across all array types with equal probability.

Eye tracking procedure.—Eye tracking data were collected using a Dell laptop (15.5” screen) with a Tobii x3–120 tracker that utilizes corneal reflections and does not require any head-mounted equipment or physical constraints. Stimulus presentation was controlled using Tobii Studio v. 3.4. A 5-point calibration procedure was implemented prior to collecting gaze data. The procedure took on average ~30 sec and could be repeated as needed to achieve adequate data quality. Each of the 12 visual arrays was presented for 10 sec each with 1 sec inter-trial interval marked by a white fixation point presented in the center of a black screen. Participants were tested individually in a quiet room while positioned approximately 20 inches from the eye tracker. They viewed one of four possible sequences of the arrays and were instructed to watch the screen “like TV”. No image-specific instructions were provided. The entire acquisition procedure, including calibration, lasted less than 5 minutes. All data were acquired within 90 minutes after the most recent regular meal or snack.

Data Analysis

Using Tobii Studio software tools, each participant’s eye gaze data were automatically scored for 24 regions of interest corresponding to the individual items in each visual array. A fixation was defined as having a radius of at least 50 pixels (visual angle of approximately 2.5°) and the minimum duration of 100 msec. Following the procedures of Key & Dykens (2018), only data from the arrays containing pictures of foods were included in analyses. Visual attention to food items was quantified in the context of other high-interest (animals) and low-interest stimuli (household objects) as the number of items looked at within each category, total duration of fixations, and the number of gaze returns to a particular item after looking away (see Table 2 for summary data).

The resulting three dependent measures were analyzed separately using repeated measures ANOVA with Stimulus (2: food vs. objects/animals) × Contrast Type (2: high interest, low interest) as the within-subject factors. Group (2: PWS, TD) and Sex (2: male, female) served as the between-subject factors. There were no significant differences in the eye gaze variables between the two sites; therefore study site was not included as a separate factor in the analysis.

Significant interactions were followed up with pairwise t-tests and one-way ANOVAs with Bonferroni correction for multiple significance testing. Pearson correlations were used to test for the predicted positive association between the eye tracking variables (food items) and behavioral characteristics (IQ, BMI, hyperphagia, nutritional phase) of the participants with PWS.

Results

Total Number of Items Explored

There was a main effect of Group, $F(1,100)=69.322$, $p<.001$, $\eta_p^2=.409$, as well as a Stimulus x Contrast Type interaction, $F(1,100)=47.106$, $p<.001$, $\eta_p^2=.320$, and a Contrast Type x Group interaction, $F(1,100)=7.556$, $p=.007$, $\eta_p^2=.070$. Follow-up analyses in the combined sample found a greater number of food items explored compared to the household objects (low-interest contrast), $t(103)=4.335$, $p<.001$, $d=.43$, while more animals (high-interest contrast) were explored compared to food, $t(103)=5.549$, $p<.001$, $d=.54$. The number of fixations on food items was also greater in the low-interest than high-interest arrays, $t(103)=5.413$, $p<.001$, $d=.53$.

Between-group differences were due to the higher number of items explored by typical children compared to participants with PWS in high- and low-interest contrast types, $F(1,102)=52.280$, $p<.001$ and $F(1,102)=68.502$, $p<.001$, respectively. There were no contrast-related differences in the number of items explored for children with PWS (p=.175), while typical children explored more items in the trials involving low-interest than high-interest contrasts, $t(46)=2.301$, $p=.026$, $d=.34$.

Total Duration of Fixations

There was a main effect of Group, $F(1,100)=45.137$, $p<.001$, $\eta_p^2=.311$, as well as a Stimulus x Contrast Type interaction, $F(1,100)=42.067$, $p<.001$, $\eta_p^2=.296$, and a Contrast Type x Sex x Group interaction, $F(1,100)=4.049$, $p=.047$, $\eta_p^2=.039$. Follow-up analyses found longer fixations in typical participants compared to children with PWS. In the combined sample, food items had longer fixations compared to the household objects (low-interest contrast), $t(103)=4.542$, $p<.001$, $d=.45$, while animals (high-interest contrast) were fixated upon longer compared to food, $t(103)=3.823$, $p<.001$, $d=.39$. The duration of fixations on food items was longer in the low-interest than high-interest arrays, $t(103)=4.903$, $p<.001$, $d=.48$.

Following up on the Contrast Type x Sex x Group interaction, within-group analyses revealed that significant sex-related differences were present for children with PWS, $F(1,55)=5.771$, $p=.020$, $\eta_p^2=.095$, where males had longer fixations than females on low-interest contrast trials, $F(1,55)=7.709$, $p=.007$ (6.30 vs. 4.33 sec). The same interaction was not significant in the typical group. There were no PWS vs. TD group differences in fixation duration for males or females. Contrast-related difference in the duration of fixations was significant in females with PWS only, who had longer fixations during the high-interest than low-interest trials, $t(34)=2.187$, $p=.036$, $d=.37$. Neither males with PWS ($p=.202$) nor typical children of both sexes (p=.315−.628) showed this difference.

Number of Gaze Returns

There was a main effect of Group, $F(1,100)=63.976$, $p<.001$, $\eta_p^2=.390$, as well as a Stimulus x Contrast Type interaction, $F(1,100)=57.449$, $p<.001$, $\eta_p^2=.365$, and a Stimulus x Group interaction, $F(1,100)=4.393$, $p=.039$, $\eta_p^2=.042$. Follow-up analyses in the combined sample found a greater number of gaze returns to food items compared to the household objects (low-interest contrast), $t(103)=5.315$, $p<.001$, $d=.52$, while more returns were made to animals (high-interest contrast) than to food, $t(103)=5.349$, $p<.001$, $d=.52$. The number of returns to food items was also greater in the low-interest than high-interest arrays, $t(103)=5.217$, $p<.001$, $d=.51$.

Typical children made more gaze returns than the PWS group to both food, $F(1,102)=39.610$, $p<.001$, and non-food stimuli, $F(1,102)=76.356$, $p<.001$. Participants with PWS made more gaze returns to food than objects, $t(56)=4.252$, $p<.001$, $d=.56$, while typical children revisited animal items more often than food, $t(46)=3.998$, $p<.001$, $d=.58$. The latter contrast in the PWS group demonstrated the same pattern but did not survive correction for multiple significance testing (uncorrected $p=.042$, $d=.28$).

Deletion vs. mUPD subtype differences

To explore the potential genetic differences in Visual Exploration task performance in the PWS group, we repeated the analyses described above with the Subtype (2: Deletion, mUPD) as the between-subject factor. There were no additional significant effects except for the main effect of Subtype for total fixation duration, $F(1,48)=4.243$, $p=.045$, $\eta_p^2=.081$, due to longer fixations in the mUPD than deletion subgroups.

Correlations Between Eye Tracking and Behavioral Measures

We examined the association between eye gaze measures and IQ, nutritional phase, hyperphagia questionnaire (HQCT) scores, and BMI. In the PWS group, while controlling for the genetic subtype, a higher number of food items explored, longer fixation duration, and greater number of gaze returns for both high- and low-interest contrasts were associated with later nutritional phase and higher HQCT score (number of items in high-interest contrast only (see Table 3). Further examination of these associations within each genetic subtype revealed that in the deletion groups, the expected positive associations between the gaze metrics for food items and nutritional phase and HQCT scores were observed mainly for the high-interest contrasts. Conversely, in the mUPD group, similar correlations were observed for the low-interest contrasts.

Discussion

This study examined eye gaze patterns to food and nonfood items in children with PWS compared to typical children and assessed sensitivity of the visual exploration data to hyperphagia and the individual's nutritional phase. The results indicate that during free visual exploration of stimulus arrays, children with PWS did not allocate greater than typical attention to food items. Consistent with the findings of Key and Dykens (2018), for both participant groups, food was more interesting that objects but less than animals. In children with PWS, increased hyperphagia and more advanced nutritional phase were associated with greater visual attention to food in the presence of other high-interest items.

Compared to the typical group, children with PWS explored fewer stimulus items across all image categories, spent less time looking at the images, and in general, demonstrated fewer gaze returns to previously seen stimuli. It is possible that children with PWS were more inattentive during the study procedure; however, the design comparing gaze data between food and nonfood items within each subject minimized the potential confounding effects of the variable attention levels. The absence of a greater than typical attention to food items in children with PWS may appear counterintuitive in the context of hyperphagia and the associated behavioral evidence of increased interest in food. One explanation could be based on the fact that all participants were tested in satiated state (i.e., within 90 minutes of the most recent meal or snack). The results could also be interpreted to suggest that food is not the only stimulus category that persons with PWS find interesting. Reduced understanding of the task is not a likely explanation given the passive nature of the visual exploration paradigm that did not require comprehension of instructions and relied on free viewing of the stimuli rather than on goal-directed attention.

We did observe sex and genetic subtype differences within the PWS group. Females with PWS demonstrated longer fixation durations for high-interest (food and animals) than low-interest (food and objects) contrasts. This difference was not significant in males due to longer duration of fixations on the low-interest contrasts. Also, participants with the mUPD subtype had longer fixations on all stimulus types than the deletion subgroup. There were no significant differences in sex distribution between the genetic subgroups.

In line with the hypothesized associations, we observed positive correlations between increased hyperphagia and greater visual attention to food compared to other high-interest items in the combined PWS sample. These results replicate the findings of Key and Dykens (2018) and suggest that while noticing food among inanimate objects may be evolutionary adaptive (e.g., Nijs et al., 2010), increased attention to food above and beyond the other salient stimuli (e.g., animals) may indicate an atypical motivational system. Examination of these associations within each genetic subtype demonstrated that in the deletion subgroup, greater relative salience of food vs. animals was related to increased hyperphagia and later nutritional phases, while in the mUPD group, similar associations were observed more often for the food vs. objects contrasts. These findings, in the absence of subtype differences in hyperphagia scores from caregiver reports, support the notion that increased attention to food relative to other salient stimuli may be indicative of atypical eating behaviors. Persons with the deletion subtype are more likely to exhibit nurturing tendencies while individuals with the mUPD subtype demonstrate increased autism characteristics and thus may be more interested in objects (e.g., computers, vacuum cleaners, remotes) than animals. Of note, reexamination of data in Key and Dykens (2018) noted a similar pattern of subtype-related differences in the stimulus contrasts that were most informative about hyperphagia.

Previously, increased reward salience of food cues vs. other affective stimuli was related to greater compulsive food seeking (Yager & Robinson, 2010) and cue-induced eating (Versace et al., 2018). Similarly, increased salience of cigarette-related images relative to other pleasant stimuli was associated with greater likelihood of relapse in smokers trying to quit (Versace et al., 2014, 2016). The ‘wanted’ stimuli capture attention and motivate behavior through involvement of amygdala, orbitofrontal cortex, prefrontal cortex, and basal ganglia (e.g., Murdaugh, et al., 2012; Siep, et al., 2009). Many of the same regions are engaged in the control of eye movements (Luna, 2008), making eye tracking an effective means to assess motivated attention. Furthermore, these cortical and subcortical structures control the autonomic nervous system via brainstem (e.g., Eckstein, et al., 2017; LeDoux, 1987).

Studies of autonomic function are limited in individuals with PWS. Reported evidence of increased pain thresholds, daytime sleepiness, as well as altered heart rate, pupillary, and electrodermal responses suggest diminished parasympathetic activity (DiMario et al.,1994; Haqq et al., 2012) and overactivation in sympathetic system (Chevalere et al. 2019). Thus, future studies of hyperphagia in PWS may consider incorporating pupillometry (already supported by many modern eye tracking systems), skin conductance, and heart rate measures to gain additional information about autonomic responsiveness to motivationally salient stimuli (e.g., Sirois & Brisson, 2014, Mauler et al., 2006).

An additional aim of this study was to examine scalability of the eye tracking paradigm. Two sites collected data in parallel using the same equipment and experimental protocol, and the dependent measures were derived using automated routines in Tobii Studio. The analyses identified no significant differences between the sites in any of the gaze metrics, supporting feasibility of implementing this eye tracking paradigm across research groups and laboratory settings.

Together, our results suggest that eye tracking during visual exploration is a promising objective measure of hyperphagia in PWS. To date, it has been validated against the available behavioral assessments (caregiver reports and clinical opinion), replicated in two different samples of children and adults with PWS, and yielded similar results when used by two separate research groups. The next steps in establishing eye tracking as a clinically useful measure for hyperphagia treatment outcome evaluation would include establishing reliability of the gaze metrics and their sensitivity to individual differences in physiological states associated with hunger and satiety. In the present study, eye tracking data were collected in recently fed subjects during a single visit, precluding evaluation of test-retest stability or sensitivity to differences in satiety. Previously, Key & Dykens (2018) reported good stability of the eye tracking for food stimuli in PWS over a 2-day period. With most treatment studies looking to document effects either on a shorter time scale (e.g., within the same day) or involving longer treatment periods, future eye tracking studies will need to evaluate stability of the identified variables over these varied time frames. Similarly, previous studies in non-PWS populations reported changes in gaze patterns for food stimuli between hunger and satiety states (Castellanos et al., 2009; Nijs et al., 2010). Given the existing evidence suggesting possible alterations in the underlying physiology of hunger in PWS (Holsen et al., 2011), it will be important to examine whether the eye tracking metrics of food salience change from before to after a meal. Finally, follow-up studies will need to replicate sex and genetic subtype differences observed in the current study.

In conclusion, this study demonstrated that eye tracking during a brief visual exploration paradigm is a feasible means to directly and objectively characterize hyperphagia in persons with PWS. In addition to complementing informant-based reports and clinical judgment, gaze data indicate that examining food salience in the context of other high-interest items may be particularly relevant for evaluating hyperphagia. Increasing accessibility of eye tracking equipment in combination with the current evidence of successful paradigm implementation across research groups and testing settings make gaze data a cost-effective measure for use in future treatment studies.

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Data Availability

The data that support the findings of this study are available from the corresponding author (AK) upon reasonable request.

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Figure 1.
A sample stimulus array with the individual areas of interest marked for each item.

Table 1.

Demographic characteristics of the participants by study site and in the combined sample.

Site	Group		Age (yrs)	BMI	Nutritional Phase	HQCT	KBIT
VUMC	PWS (n=25)	M	7.32	20.31	4.16	21.44	72.92
		SD	2.32	5.60	0.85	7.41	13.18
	TD (n=17)	M	7.08	18.37	n/a	12.59	110.41
		SD	2.83	5.47		3.66	14.39
CWRU	PWS (n=32)	M	5.53	17.40	3.00	16.16	75.81
		SD	2.46	3.26	0.76	6.65	13.79
	TD (n=30)	M	7.50	16.87	n/a	11.40	114.38
		SD	3.15	2.82		3.48	12.01
Total	PWS (n=57)	M	6.32	18.72	3.51	18.47	74.55
		SD	2.54	4.67	0.98	7.42	13.48
	TD (n=47)	M	7.35	17.41	n/a	11.83	112.81
		SD	3.01	3.99		3.55	12.99

VUMC – Vanderbilt University Medical Center; CWRU – Case Western Reserve University, PWS – Prader-Willi syndrome, TD – typical development, BMI – body mass index, HQCT – Hyperphagia Questionnaire-Clinical Trials, KBIT – Kaufman Brief Intelligence Test

Table 2.

Summary gaze data (means, standard deviation) for food and non-food items quantified as the number of individual items looked at, total duration of fixations, and the number of gaze returns to individual items.

		PWS (N=57)		TD (N=47)	
		M	SD	M	SD
number of items fixated	FA_Food	11.39	4.28	16.43	5.66
	FA_Animals	13.65	5.53	20.70	5.03
	FO_Food	13.32	5.60	21.34	7.39
	FO_Objects	10.51	4.25	19.11	6.37
fixation duration	FA_Food	4.83	3.23	7.27	2.88
	FA_Animals	5.60	3.78	10.06	3.41
	FO_Food	5.93	3.52	9.43	3.65
	FO_Objects	4.26	2.92	7.49	2.95
number of gaze returns	FA_Food	15.33	6.74	23.81	8.90
	FA_Animals	19.26	9.40	31.26	8.66
	FO_Food	18.88	8.82	29.02	9.94
	FO_Objects	13.65	6.12	25.47	7.73

FA – Food-Animal arrays, FO – Food-Object arrays, PWS – Prader-Willi syndrome, TD – typical development

Table 3.

Correlations between eye gaze measures for food items and IQ (KBIT), nutritional phase, hyperphagia questionnaire (HQCT) scores, and BMI in the combined PWS sample (controlling for the genetic subtype) and for each genetic subtype.

	All PWS (controlling for subtype)				Deletion only				mUPD only			
	KBIT	**NutPhase**	**HQCT**	**BMI**	**KBIT**	**NutPhase**	**HQCT**	**BMI**	**KBIT**	**NutPhase**	**HQCT**	**BMI**
KBIT		−0.150	−.219	−.089		−.097	−.151	.090		−0.311	−0.359	−.611**
Nutritional Phase			.777**	.441**			.816**	.422*			.637**	.502*
HQCT				.402**				.393*				.465*
FA_ number	−.011	.364**	.231	−.005	−.183	.308*	.316*	.068	.489*	.293	−.006	−.280
FA_ fix_dur	.010	.320*	.198	0.160	−.136	.471**	.276	.353*	.259	−.147	.082	−.370
FA_ returns	−.066	.366**	.213	.0290	−.230	.360*	.322*	.108	.318	.236	−.029	−.203
FO_ number	.187	.256*	.125	.182	.292*	.181	.201	.213	−.075	.477*	.016	.163
FO_ fix_dur	.202	.280*	.157	.184	.274	.279	.259	.300*	.089	.165	−.018	−.082
FO_ returns	.208	.353**	.163	.194	.269	.287*	.230	.247	.049	.528*	.039	.096

* $p<.05$,

** $p<.01$

FA – Food-Animal arrays, FO – Food-Object arrays, PWS – Prader-Willi syndrome, TD – typical development

Number – number of items fixated, fix_dur – fixation duration, returns – number of gaze returns to the same item