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SHORT REPORT

Pubertal development shapes perception of complex facial expressions

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Abstract

We previously hypothesized that pubertal development shapes the emergence of new components of face processing (Scherf et al.*, 2012; Garcia & Scherf, 2015). Here, we evaluate this hypothesis by investigating emerging perceptual sensitivity to complex versus basic facial expressions across pubertal development. We tested pre-pubescent children (6–8 years), age- and sex-matched adolescents in early and later stages of pubertal development (11–14 years), and sexually mature adults (18–24 years). Using a perceptual staircase procedure, participants made visual discriminations of both socially complex expressions (sexual interest, contempt) that are arguably relevant to emerging peer-oriented relationships of adolescence, and basic (happy, anger) expressions that are important even in early infancy. Only sensitivity to detect complex expressions improved as a function of pubertal development. The ability to perceive these expressions is adult-like by late puberty when adolescents become sexually mature. This pattern of results provides the first evidence that pubertal development specifically influences emerging affective components of face perception in adolescence.*

Research highlights

- We tested the influence of pubertal development on the ability to detect facial expressions.
- Prepubescent children, adolescents in early and late puberty, and sexually mature adults were tested in a perceptual staircase paradigm.
- The ability to detect happy and anger is not related to puberty.
- The ability to detect sexual interest and contempt is shaped by puberty.
- This is the first study to show that puberty shapes development of visual perception.

Introduction

Adolescence begins with the onset of pubertal development and ends with the acquisition of adult social roles (Dahl, 2004). This is a transformative period in terms of physical development. Perhaps less obvious is the influence of puberty on the developing behaviors related to the acquisition of adult social roles. These include acquiring autonomy from parental figures, developing confiding peer friendships, and exploring romantic/sexual relationships (Havighurst, 1972; Roisman, Masten, Coatsworth & Tellegen, 2004). Previously, we hypothesized that pubertal development influences the emergence of new components of social information processing that support the acquisition of these behaviors, particularly in the domain of face processing (Scherf, Behrmann & Dahl, 2012; Scherf & Scott, 2012; Garcia & Scherf, 2015). Here, we empirically evaluate this hypothesis by investigating emerging sensitivity to facial expressions across pubertal development.

Facial expressions provide critical signals about internal states and feelings. *Complex* facial expressions convey signals about nuanced emotions and mental states (Baron-Cohen, Wheelwright, Hill, Raste & Plumb, 2001; Shaw, Bramham, Lawrence, Morris, Baron-Cohen *et al*., 2005), many of which are relevant for the new peer-oriented relationships in adolescence. For example, the coy smile (half smile with lowered eyes) is a signal of flirtatiousness, and the eyebrow flash with a smile is a signal of sexual

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interest (Eibl-Eibesfeldt, 1973). We suggest that these expressions only become relevant to an individual once interest in romantic/sexual relationships emerges (Garcia & Scherf, 2015), which typically begins in adolescence. Similarly, other kinds of complex expressions provide signals about the status of confiding relationships. For example, unilateral raising and tightening of the lip corner signals contempt (Ekman & Friesen, 1986), a violation of loyalty. Sensitivity to these kinds of complex expressions may become especially important as adolescents focus on developing peer-oriented relationships.

Here, we tested the hypothesis that pubertal development shapes the way adolescents perceive these kinds of complex facial expressions. The study was organized around two goals. First, to evaluate the most basic component of emotion expression processing; that is, visual perception of the expressions. Previous studies required participants to verbally label an expression, which requires having a semantic representation for each label (e.g. Vetter, Leipold, Kliegel, Phillips & Altgassen, 2013; Kessels, Montagne, Hendriks, Perrett & Haan, 2014; Rodger, Vizioli, Ouyang & Caldara, 2015). We predicted that pre-pubescent children and even some adolescents would not have such representations for the very expressions we were evaluating (e.g. sexual interest). As a result, we used a perceptual staircase procedure (Cornsweet, 1962) in which participants made simple visual discriminations about 'which face shows more expression?' This allowed us to identify participants' perceptual threshold of the just-noticeable difference for each expression from a neutral face. In this way, we quantified the amount of perceptual information, not semantic or verbal information, that each participant needed to detect each expression.

Second, to assess the influence of pubertal development on the perception of complex expressions, we employed a novel design that was inspired by previous work investigating the influence of pubertal development on brain development (Bramen, Hranilovich, Dahl, Forbes, Chen *et al*., 2011; Herting, Gautam, Spielberg, Dahl & Sowell, 2015). Between the ages of 11 and 14 years, there is extensive variability in the timing and tempo of pubertal development (Marceau, Ram, Houts, Grimm & Susman, 2011). In fact, individuals in nearly every stage of puberty are present in this narrow age range (Susman, Houts, Steinberg, Belsky, Cauffman *et al*., 2010). We recruited two groups of adolescents, who were matched on age (12-year-olds) and sex, but differed in pubertal development (early versus late puberty). In fact, the participants in the two groups exhibited no overlap in pubertal stage. This design ensured that differences between the adolescent groups could be attributed to pubertal development, not age. We also tested pre-pubescent children (i.e. as verified by parental report) and sexually mature adults in order to sample the full range of pubertal status. Importantly, in contrast to all previous studies that reported a link between pubertal development and some component of face perception (Diamond, Carey & Back, 1983; McGivern, Andersen, Byrd, Mutter & Reilly, 2002; Vetter *et al*., 2013; Lawrence, Campbell & Skuse, 2015), we assessed pubertal status in males and females by collecting both adolescent- and parent-report on two separate measures, the Sexual Maturation Scale (SMS; Morris & Udry, 1980) and the Pubertal Development Scale (PDS; Petersen, Crockett & Richards, 1988), and evaluated evidence of both adrenarche and gonadarche when determining an overall stage of pubertal development for participants. Also, unlike these previous studies, we tested an equal number of boys and girls in each of the developmental groups so that sex differences in the sample could not explain group differences.

Here, we predicted that relative to developing sensitivity to basic expressions, like *happy* and *anger*, sensitivity to complex expressions would change sharply as a function of emerging pubertal development, but more importantly, improve specifically as a function of pubertal development throughout adolescence. We predicted that adolescents in later stages of pubertal development would show lower perceptual thresholds to detect complex expressions, particularly those that are relevant to the dynamics of the new peer relationships in adolescence, than would age-matched adolescents in earlier stages of pubertal development. As a result, we chose the complex expressions of *sexual interest*, given the newly emerging interest adolescents have in romantic and sexual relationships, and *contempt*, which signals violations of loyalty and may be especially important to adolescents as they forge intense confiding peer friendships. In contrast, we predicted that sensitivity to detect basic expressions may improve as a function of age particularly earlier in development, but importantly, would *not* be related to pubertal development. This prediction stems from evidence that perceptual sensitivity to detect happy is stable early in development (Rodger *et al*., 2015) and our hypothesis that the steepest learning curve for perceptual sensitivity to basic expressions is in infancy, given the importance of basic expressions in facilitating and supporting relationships with caregivers (Garcia & Scherf, 2015).

Methods

Participants

A total of 112 participants were tested. The demographic characteristics of the four groups are in Table 1. An

Table 1 *Demographic characteristics of the four developmental groups*

Pubertal group	Males *N*	Females *N*	*M* Age (*SD*)	Range
Pre-pubescent children	14	14	7.14 (0.65)	6–8 yrs
Early puberty adolescents	14	14	11.50 (0.64)	11–13 yrs
Late puberty adolescents	14	14	11.86 (0.97)	11–14 yrs
Sexually mature adults	14	14	19.46 (1.48)	18–24 yrs

additional 13 children were tested and excluded due to experimenter error (6), because they were higher than Tanner Stage 1 in pubertal development (6), or failed to complete the experiment (1). An additional four adolescents were excluded due to a lack of agreement among informants about pubertal status. The adolescent groups were matched on age, $t(54) = -1.6$, $p = .110$ (Figure 1a), but differed in pubertal status, $t(54) = -12.4$, $p < .001$ (Figure 1b).

Participants were medically healthy, free of regular medication use, and had no history of: autism, neurological or psychiatric illness, acquired brain injury, learning disabilities, developmental disabilities, school problems, or substance abuse in themselves or their first-degree relatives. Child and adolescent participants were recruited through the Families Interested in Research Studies (FIRSt) database at Penn State University and through several outreach initiatives. Adult participants were recruited via print advertisements and the PSU Psychology Department undergraduate subject pool. All participants were paid $10 for their participation with the exception of the subject pool participants who received 1 credit hour. Informed consent was obtained from participants and parents of children and adolescents, along with assent from the youngest children, using procedures approved by the Internal Review Board of Penn State University.

Materials

Pubertal assessments

Assessments of pubertal development were acquired for both children and adolescents. Parents provided assessments of children, and both parents and adolescents provided assessments of pubertal development for the adolescents. In this way, we acquired multi-rater and multi-measure assessments of pubertal development in the adolescents.

The pubertal development measures assessed developing secondary sex characteristics. They included the self/parent report version of the Sexual Maturation Scale (SMS; Morris & Udry, 1980), which comprises line drawings of five progressive stages of pubertal development: stage 1 (pre-pubescent) to stage 5 (adult appearance). For males, the drawings combine pubic hair and genital development. For females, the drawings include pubic hair and breast development. The Pubertal Development Scale (PDS) is a written questionnaire that assesses multiple aspects of pubertal development, including growth spurt, body hair and skin changes, breast development and menstruation, for girls, and voice changes and facial hair, for boys (Petersen *et al.*, 1988). Both of these measures have been used to assess pubertal status in recent developmental studies (e.g. Bond, Clements, Bertalli, Evans-Whipp, McMorris *et al.*, 2006; Hibberd, Hackney, Lane & Myers, 2014; Saxbe, Negriff, Susman & Trickett, 2015) and are reported to be in moderate agreement with physical

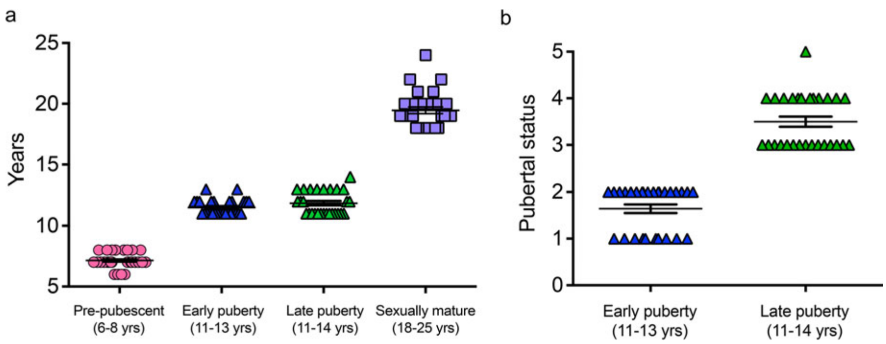

Figure 1 *Adolescents differed in pubertal status but not age. The two groups of adolescents were matched on age* (p > *.10) (a), but differed in pubertal status* (p < *.001) (b). Pubertal status was computed using a composite score from both parent-report and adolescent self-report on two measures of pubertal development. Responses were converted to a 5-point scale (1 = Pre-pubescent, 5 = Sexual Maturity). All four measures were required to consistently categorize adolescents into either the early (stages 1–2) or later (stages 3–5) groups for the adolescent to be included in the study.*

exams by clinicians and basal hormone levels (see Shirtcliff, Dahl & Pollak, 2009).

Expression stimuli

The facial expression stimuli included static grayscale images of a professional young adult actress composing multiple expressions, including two neutral faces (closed mouth, open mouth) as well as two basic (angry, happy) and two complex (contempt, sexual interest) expressions, one positively and one negatively valenced expression from each category. We chose a single female actress to compose all the expressions for two reasons. First, using different face identities for each expression could have induced identity by expression interactions. Second, the expression of sexual interest is typically signaled by women (Grammer, Kruck, Juette & Fink, 2000), but is detected by both men and women (Moore, 1985). The actress was 19 years old at the time that the photographs were taken. We specifically chose a person whose age was somewhat ambiguous in terms of whether she is an older adolescent or a younger adult. In this way, both the adolescents (early and late because they are the same age) and the college-aged young adult participants could potentially conceive of her as a 'peer'. This was intended to minimize the extent to which there might be a peer bias in processing facial expressions for both adolescents and adults, even though this bias has not been reported in the literature previously.

In each expression, the actress looked directly at the camera. The hair, neck, and shoulders were removed and luminance was normalized across images (see Figure 2). Each 100% expression was rated by an independent group of 90 adults to ensure the expressions were unambiguous (see Supplementary Text). Each of the four 100% emotional expressions was separately morphed with a neutral expression using Abrosoft Fantamorph 5 Deluxe (Version 5.4.0). This procedure generated 14 unique morphs per expression (see Figure 2).

Procedure

For child participants, parents completed the SMS. For adolescent participants, both the adolescent and parent were each provided with separate sealed envelopes, which contained the two pubertal development questionnaires. The researcher left the room to provide adolescents and parents privacy while completing the measures. Adolescents and parents returned the forms to the researcher in their respective sealed envelopes. Following completion of these measures, participants completed the behavioral task.

Just-Noticeable Difference (JND) task

This task was designed to measure the minimum amount of perceptual information (i.e. perceptual threshold) necessary to discriminate each expression from a neutral face. It was a two-alternative forced-choice fixed step-size perceptual staircase procedure (Cornsweet, 1962) and was conducted on a MacBook Pro computer (12-inch monitor) using MATLAB with Psychophysics Toolbox (Brainard, 1997). The task began with four practice trials in which each of the 100% expressions was paired with a neutral face. Participants identified, 'Which face shows more expression?' and were required to respond correctly on each practice trial prior to beginning the experiment. For all pediatric participants, the experimenter ensured task instructions by asking: 'Do you know what an expression is? Can you show me?' If the answer was negative, the researcher explained, 'An expression is the

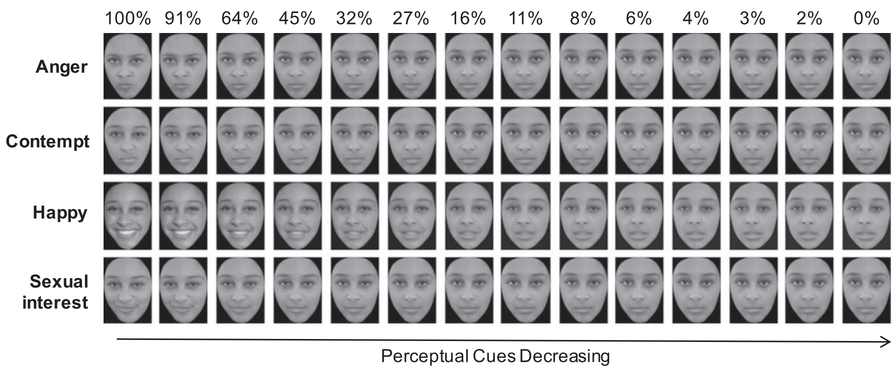

Figure 2 *Facial expression stimuli. Each of the four 100% emotional expressions was separately morphed with a neutral expression. This procedure generated 14 unique morphs per expression (1%, 2%, 3%, 4%, 6%, 8%, 11%, 16%, 27%, 32%, 45%, 64%, 91%, and 100%) for each of the four expressions.*

way you show what you're feeling on your face. If you're happy, you smile. If you're sad, what do you do then? Can you show me?'

During the task, on each trial, participants saw a central fixation and a pair of face stimuli, one directly above and the other directly below the fixation. Participants decided 'which face shows more expression' with a button press. The pair of stimuli included the neutral face and one of the morphed facial expressions. The position of the stimuli was counterbalanced across trials. The first trial included the neutral and the 64% morph (see Figure 2). The staircase procedure proceeded with a 1-down/2-up step size along a $\log_2$ function until the participant experienced five failures. For each failure, a perceptual threshold was computed as the average of the morphed stimulus from the failed trial and that from the most recent successful trial. For example, if a participant failed at a trial in which the 32% morph was presented the perceptual threshold would be computed as (45% + 32%)/2 = 38.5%. The final perceptual threshold was computed as the average of the five thresholds. We determined that five failures was an appropriate stopping rule for the staircase procedure in this experiment by pilot testing with an independent set of adult and child participants. This criterion appropriately balanced the subject variability, but also interdependence of responses, like anchoring effects and adaptation-level phenomena, perseveration, and anticipation (Cornsweet, 1962). The number of trials to criterion for each group and expression is reported in Supplementary Table 1.

Each expression was tested in a separate block that began with an image depicting the 100% version of the expression being tested in the block with the instructions, 'Now you will see this expression.' The order of the blocks was counterbalanced across participants.

Data analysis

Pubertal assessments

Only children who were identified as being in Tanner stage 1 were included in the sample of pre-pubescent children. In order to take advantage of the multi-rater and multi-measure approach to assessing pubertal status, we designed a composite score for assigning adolescents into the early and late pubertal groups. We converted both sets (parent, self-report) of PDS responses to parallel the SMS scoring (Shirtcliff *et al.*, 2009), which resulted in four measures of pubertal development on a 5-point scale (1 = pre-pubescent, 5 = sexual maturity). As in previous work, we categorized adolescents into either an early (Tanner stages 1–2) or late (Tanner stages 3–5) puberty group (Bramen *et al.*, 2011; Herting *et al.*, 2015). Unlike previous studies, we used all four scores and required them to be consistent when categorizing adolescents into these groups. For example, an adolescent in the late group could have a range of scores across the four measures (e.g. 5 self-PDS, 4 self-SMS, 3 parent-PDS, 3 parent-SMS). Since all four scores fall in the late category (3–5), this adolescent would be classified as a late puberty adolescent. If, however, the adolescent and the parent reports differed across category (e.g. parent-report 2 and self-report 4), the adolescent would not have been included in the final dataset.

As indicated by self-reports, late pubertal adolescents included menstruating girls who have breasts developing, pubic hair, and skin changes, and boys with deepening of the voice, skin changes, facial hair growth, and enlargement of the testes and phallus. Early pubertal girls were not menstruating, have little to no body hair, breast development, or skin changes. Similarly, early pubertal boys had little to no body hair, deepening of the voice, or skin changes, and smaller testes and phalli.

Behavioral data

Prior to analyses, we examined the data for outliers and violations of normality separately for each expression within each pubertal group. Any data point beyond 2 *SD* of the mean for the respective group was replaced with the mean ± 2 *SD* for that expression for that group, a procedure typically used for minimizing the effects of extreme scores while maintaining the size of the sample and minimally affecting the mean of the distribution (Dixon & Tukey, 1968). Because the variance was not equal across the pubertal groups for most of the expressions, we transformed the raw perceptual thresholds by using a square root function. For each expression, this transformation normalized the variance across groups without distorting the normality of the distribution.

Mean transformed perceptual thresholds were submitted to a repeated-measures ANCOVA with valence (positive, negative) and expression type (basic, complex) as the within-subject factors and pubertal group (Pre-Pubescent, Early Puberty, Late Puberty, Sexually Mature) and sex (male, female) as between-subject factors, and age as a covariate. Interactions were evaluated by investigating simple main effects using subsequent univariate analyses with the appropriate fixed factor and age as a covariate. Finally, we bootstrapped significant main effects from the univariate analyses with 1000 iterations to determine the 95%

confidence intervals and pairwise comparisons of the fixed factor (e.g. group).

Results

Figure 3 shows the mean perceptual thresholds for each pubertal group as a function of expression type. The full set of findings from the repeated-measures ANCOVA are reported in Table 2. Here we will only describe the significant findings. The only main effect was pubertal group, $F(3, 103) = 6.0$, $p < .001$, $\eta^2 = 0.15$. This main effect was qualified by the only significant interaction of expression type × pubertal group, $F(3, 103) = 4.0$, $p = .005$, $\eta^2 = 0.11$. Given that there were no main effects of sex or valence, and no interactions with these variables, we collapsed across both of them for the follow-up analyses.

To examine the interaction between expression type and pubertal group, we investigated the simple main effect of group within each expression type in separate univariate models. In each of these models, pubertal group was the fixed factor and age was a covariate. In the analysis on perceptual thresholds for basic expressions, there was no main effect of pubertal group, $F(3, 107) = 0.95$, $p > .10$, or age $F(1, 107) = 1.8$, $p > .10$. In stark contrast, however, the analysis on perceptual thresholds for complex expressions revealed a main effect of pubertal group, $F(3, 107) = 7.9$, $p < .001$, $\eta^2 = 0.18$, but not age, $F(1, 107) = 0.18$, $p > .10$. To determine the degree to which the groups differed in perceptual thresholds for complex expressions, we computed the 95% confidence intervals (*CI*) (see Table 2b). Pre-pubescent children had higher thresholds than all groups ($p < .025$) (i.e. non-overlapping CIs). Early puberty adolescents had higher thresholds than both late puberty adolescents ($p < .005$) and sexually mature adults ($p < .05$). Late puberty adolescents and sexually mature adults had comparable thresholds ($p > .10$) (i.e. overlapping CIs). This pattern of results indicates that the transition from early pubertal development (not age) during adolescence selectively influences perceptual sensitivity to detect complex, but not basic, expressions.

Discussion

In the current study, we tested the hypothesis that pubertal development shapes the way adolescents perceive socially complex facial expressions, namely sexual interest and contempt. To do so, we employed a perceptual staircase procedure in which all participants made simple visual discriminations about ‘which face

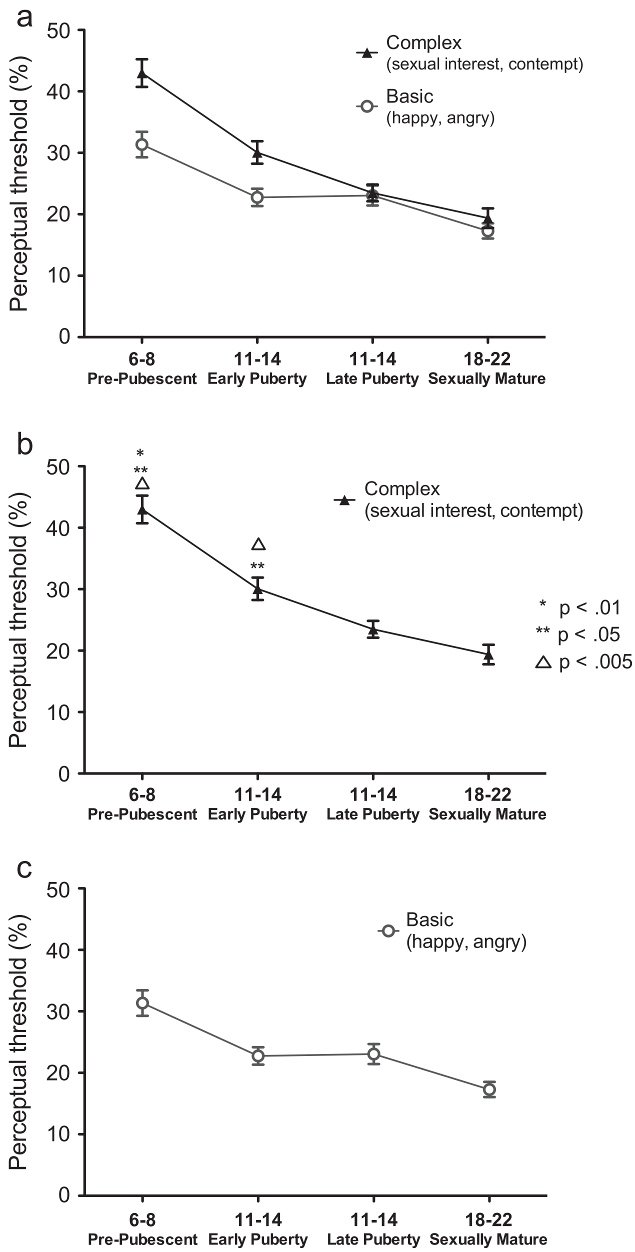

Figure 3 *Perceptual thresholds change differentially for basic and complex facial expressions across pubertal stage. (a) The mean perceptual thresholds are plotted as a function of expression type (basic and complex) and pubertal group. (b) The mean perceptual thresholds for each pubertal group to detect complex expressions. Pre-pubescent children are significantly different from early pubertal adolescents (*). Pre-pubescent children and early pubertal adolescents are both significantly different from adults (**) and early pubertal adolescents are significantly different from late pubertal adolescents (Δ). However, late puberty adolescents and adults are not different from each other. (c) The mean perceptual thresholds for each pubertal group to detect basic expressions. All of the groups were comparable in performance to detect basic expressions when age was a covariate in the omnibus analysis.*

Table 2a *Full set of results from Omnibus ANCOVA*

	df	F	p	η^2
Main effects				
Valence (Positive, Negative)	1, 103	2.246	0.137	0.021
Expression type (Basic, Complex)	1, 103	0.457	0.501	0.004
Pubertal group	**3, 103**	**6.00**	**<.001**	**0.148**
Sex	1, 103	0.673	0.414	0.006
Age	1, 103	0.003	0.954	0.000
Interactions				
Valence × Age	1, 103	0.008	0.927	0.000
Valence × Pubertal group	3, 103	1.544	0.208	0.043
Valence × Sex	1, 103	0.004	0.950	0.000
Valence × Pubertal group × Sex	3, 103	1.409	0.244	0.039
Expression × Age	1, 103	1.183	0.279	0.011
Expression × Pubertal group	**3, 103**	**4.028**	**0.009**	**0.105**
Expression × Sex	1, 103	0.673	0.414	0.006
Expression × Pubertal group × Sex	3, 103	1.033	0.381	0.029
Valence × Expression	1, 103	0.112	0.738	0.001
Valence × Expression × Age	1, 103	0.046	0.831	0.000
Valence × Expression × Pubertal group	3, 103	0.012	0.998	0.000
Valence × Expression × Sex	1, 103	0.191	0.663	0.002
Valence × Expression × Pubertal group × Sex	3, 103	1.392	0.250	0.039

Note: Within-subjects factors included valence (positive, negative), expression type (basic, complex). Between-subjects factors included sex (male, female), pubertal group (pre-pubescent, early puberty adolescent, late puberty adolescent, sexually mature young adult).

Table 2b *95% Confidence intervals from univariate analyses of Group × Expression type*

Basic expressions	Lower	Upper
Pre-pubescent children	3.99	5.69
Early puberty adolescents	4.26	4.91
Late puberty adolescents	4.34	5.00
Sexually mature adults	3.90	6.21
Complex expressions	**Lower**	**Upper**
Pre-pubescent children	5.78	7.70
Early puberty adolescents	5.09	5.83
Late puberty adolescents	4.51	5.15
Sexually mature adults	2.75	5.12

shows more expression?' As a result, this approach did not require that participants have a conceptual, verbal, or semantic representation of any specific expression. To evaluate the influence of pubertal development on this process, we compared the performance of two groups of adolescents who were matched on age and sex, but who differed in stage of pubertal development (i.e. 12-year-olds in early versus late puberty). We compared the adolescents' performance to that of pre-pubertal children and sexually mature adults in order to assay performance from individuals along the full spectrum of pubertal development in this task.

The ability to detect socially complex expressions emerges with and is fine-tuned by pubertal development

As hypothesized, we found a sharp decrease in the amount of perceptual information necessary to detect socially complex expressions that are particularly relevant to adolescent peer relationships (i.e. sexual interest, contempt) in the transition from pre-pubescent childhood to early pubertal adolescence. Pre-pubertal children required 30% more perceptual information than did early pubertal adolescents to detect complex social expressions (Figure 3b). Perhaps more importantly, sensitivity to detect these complex expressions continued to improve as a function of pubertal development during adolescence. Specifically, early puberty adolescents required 24% more perceptual information to detect complex expressions than did age-matched adolescents in later stages of pubertal development (Figure 3b). This profile of change in sensitivity across pubertal development existed for both the expressions of contempt and sexual interest and was not related to changes in age, as the two groups of adolescents were matched in age and age was factored into the analyses as a covariate.

The ability to perceive contempt and sexual interest is adult-like by late puberty when adolescents become sexually mature. This pattern of results provides the first evidence that during adolescence, pubertal development shapes the emergence of the ability to perceive complex social expressions. We previously hypothesized that sensitivity to perceive these particular complex expressions becomes especially important as individuals begin to focus on developing peer-oriented relationships specifically in adolescence and as a function of pubertal development (Garcia & Scherf, 2015). Here, we provide the first evidence in support of this hypothesis. Sensitivity to perceive the expression of *sexual interest* likely facilitates the newly emerging interest adolescents have in romantic and sexual relationships, whereas sensitivity to perceive the expression of *contempt* likely provides meaningful feedback about violations of loyalty in newly formed confiding peer friendships.

The ability to detect basic expressions is not related to pubertal development

In contrast, our findings indicate that perceptual detection of basic expressions is not specifically shaped by pubertal development. Once age is accounted for, there is no additional influence of pubertal development on the change in sensitivity to basic expressions. This is not to say that the ability to process basic expressions does not change with age, which has been reported previously (e.g. Lawrence *et al*., 2015; Rodger *et al*., 2015). Our results, which are generated from a unique paradigm designed to separate the influence of age and pubertal development, show that puberty does not specifically contribute to the developing ability to perceive basic expressions in childhood or adolescence. For example, early and late age-matched puberty adolescents did not differ in the amount of perceptual information necessary to detect basic emotional expressions (Figure 3c). This is in stark contrast to the earlier pattern of results in which the age-matched early and late puberty adolescents did differ in their perceptual thresholds required to detect complex expressions.

Pubertal effects on face processing behavior

Our findings provide the first evidence that pubertal development specifically influences emerging affective components of face perception. Researchers have previously implicated puberty as a mechanism in the developmental trajectory of face processing abilities. For example, beginning with Diamond and Carey (1977), researchers have reported a developmental 'dip' (i.e. decrease or plateau in performance) in both face identity and expression recognition abilities near age 12 that was often attributed to pubertal development (Carey, Diamond & Woods, 1980; Diamond *et al*., 1983; McGivern *et al*., 2002; Lawrence, Bernstein, Pearson, Mandy, Campbell *et al*., 2008).

Since these early findings, only a handful of studies have explicitly explored the role of puberty on the development of face perception. Diamond and colleagues reported that girls in the midst of pubertal change make more errors when identifying faces than do pre- or post-pubertal girls (Diamond *et al*., 1983). More recently, using a behavioral paradigm, researchers failed to find an effect of pubertal status on the developing ability to recognize complex emotional expressions from the eye portion of the face (Vetter *et al*., 2013). However, the study was underpowered and employed a task that primarily measures responses to complex cognitive expressions (e.g. contemplative, pensive). In contrast, Lawrence and colleagues (2015) reported that despite there being no age-related change in the ability to recognize and label the expression of anger between the ages of 6 and 16, development from mid to later stages of puberty did influence the ability to do so. However, there was a lopsided distribution of males and females in the mid-pubertal group compared to the later pubertal group, which could contribute to an interaction with the sex of the participants, and the reported effect size of the pubertal effect was very small (.03). Finally, a recent neuroimaging study reported correlations between pubertal status and neural activation to facial expressions in multiple regions of the brain in young adolescents (Moore, Pfeifer, Masten, Mazziotta, Iacoboni *et al*., 2012). However, the specificity of this pubertal effect to faces is unknown because the researchers did not compare it with processing of other stimuli.

Our findings go beyond this existing literature in several important ways. First, our experimental paradigm was specifically designed to evaluate the influence of pubertal development on the ability to perceive affective information. With the exception of the Diamond *et al*. (1983) study, this goal is unprecedented in the literature. Second, the task we employed is not a categorization task; so verbal IQ and semantic confusability do not confound our results. Our paradigm provides a clean, developmentally sensitive measure of participants' abilities to perceive and detect an emotional expression, even when they have no conceptual representation of the expression. As a result, our findings provide evidence that pubertal development shapes the actual visual perception and representation of facial expressions.

The gold standard for assessing pubertal status is physician examination, particularly in medical research. This is a very specific research setting that lends itself to the privacy, space, and specificity of interpersonal interactions with doctors and/or nurses that is fairly unique. Unfortunately, this is not feasible for most studies, including ours. Existing studies overwhelmingly use adolescent self-reports to determine pubertal status, which show moderate correlations with physician exams for identifying specific Tanner stages of pubertal development (Shirtcliff *et al*., 2009). However, it is important to note that our approach of using both parent and adolescent reports on multiple measures that assess both adrenarche and gonadarche is novel in scope and provides a new method for researchers interested in investigating the influence of pubertal development. By adding the parent report and using the scores from all four measures to categorize adolescents into the early/late puberty groups, we relied on existing measures to assess pubertal development, and also have higher confidence in the reliability of these measures to converge on a broad category of pubertal development.

Conclusions

Together, these results provide some of the first empirical evidence in support of a new theory that specifies how novel behaviors emerge as a function of pubertal development (Scherf *et al.*, 2012; Scherf & Scott, 2012). In this framework, Scherf and colleagues argued that pubertal hormones likely influence motivation to master new social developmental tasks of adolescence. In turn, the computational goals of the perceptual system change to subserve these tasks, which enables adolescents to encode new information, particularly from faces (e.g. expressions signaling the status of romantic/sexual relationships and new confiding peer friendships). The specificity of our findings that pubertal development shapes sensitivity to detect complex social, but not basic, expressions supports these hypotheses. Our findings provide the first evidence that pubertal development specifically influences emerging affective components of face perception in adolescence and, in so doing, have widespread implications for understanding how new behaviors emerge in the context of an existing complex, dynamic system.

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Supporting Information

Additional Supporting Information may be found online in the supporting information tab for this article:

Table S1. Number of Trials to Criterion for Each Expression/Category