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Association between action kinematics and emotion perception across adolescence

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Abstract

Research with adults suggests that we interpret others' internal states from kinematic cues, using models calibrated to our own action experiences. Changes in action production that occur during adolescence may therefore have implications for adolescents' understanding of others. Here we examined whether, like adults, adolescents use velocity cues to determine others' emotions, and whether any emotion perception differences would be those predicted based on differences in action production. We measured preferred walking velocity in groups of Early (11-12 years old), Middle (13-14 years old) and Late (16-18 years old) adolescents, and adults, and recorded their perception of happy, angry and sad 'point-light walkers'. Preferred walking velocity decreased across age and ratings of emotional stimuli with manipulated velocity demonstrated that all groups used velocity cues to determine emotion. Importantly, the relative intensity ratings of different emotions also differed across development in a manner that was predicted based on the group differences in walking velocity. Further regression analyses demonstrated that emotion perception was predicted by own movement velocity, rather than age or pubertal stage *per se*. These results suggest that changes in action production across adolescence are indeed accompanied by corresponding changes in how emotions are perceived from velocity. These findings indicate the importance of examining differences in action production across development when interpreting differences in understanding of others.

Keywords: Adolescence; emotion perception; body perception; action kinematics

Public significance statement

We work out how others are feeling partly by reflecting on how we feel when exhibiting body language like theirs. For example, if we see someone moving like we do when angry – usually in a faster and jerkier fashion than when we are relaxed – we attribute anger. The present study found evidence that adolescents use these movement cues similarly to adults, and therefore, because their movements are subtly different from those of adults, their emotion perception shows corresponding differences.

1. Introduction

The way we move reflects our internal states. For example, when we feel sad we move sluggishly, whereas when we feel anger our movements increase in velocity (e.g., Roether, Omlor, Christensen, & Giese, 2009b; happiness is also associated with faster movements in some [Ada, Suda, & Ishii, 2003], but not all [Barliya, Omlor, Giese, Berthoz, & Flash, 2013] studies). These kinematic signals provide a rapid route for the attribution of internal states to others (Atkinson, Dittrich, Gemmell, & Young, 2004; Atkinson, Tunstall, & Dittrich, 2007; Becchio, Koul, Ansuini, Bertone, & Cavallo, 2018; Georgiou, Becchio, Glover, & Castiello, 2007; Krumhuber & Kappas, 2005; Roether, Omlor, & Giese, 2009a), enabling fast and appropriate responses to their behavior (Brown & Brüne, 2012; Cavallo, Koul, Ansuini, Capozzi, & Becchio, 2016; Klin, Jones, Schultz, & Volkmar, 2003). Critically, recent studies have suggested that the mechanisms enabling these attributions operate via models of our own actions, such that attributions of emotion (Edey, Yon, Cook, Dumontheil, & Press, 2017) and self-confidence (Patel, Fleming, & Kilner, 2012) are distinct in those who move differently. These findings demonstrate that the way we move ourselves influences our inferences about others' internal states.

These data indicate a link in adults between some motor and social cognition processes, which suggests that the development of these two domains may not progress independently. A number of developmental findings are consistent with this notion, e.g., the age of acquisition of major motor milestones may be predictive of subsequent social capabilities (Leonard & Hill, 2014; Wang, Lekhal, Aarø, & Schjølberg, 2012; cf. Kenny, Hill, & Hamilton, 2016). However, this potential link has almost exclusively been studied in infants and young children. Studying adolescent development provides an excellent opportunity to answer questions about mechanistic links more precisely through employment of refined cognitive tasks of the type typically employed with adults, as well as shedding light on a lesser explored epoch of development.

The adolescent stage of development is marked by vast changes in social and cognitive processes (Dumontheil, 2016; Steinberg, 2005) and also dramatic changes in the physical shape and size of the body (Rogol, Clark, & Roemmich, 2000; Tanner, Whitehouse, & Takaishi, 1966). The maturation of the neuromuscular system and musculoskeletal growth result in continued refinement of motor repertoires, with differences in performance between adolescents and adults observed in a range of motor tasks (Assaiante, 2011; Davies & Rose, 2000; Largo et al., 2001; Quatman-Yates, Quatman, Meszaros, Paterno, & Hewett, 2012; Rueckriegel et al., 2008; Visser, Geuze, & Kalverboer, 1998; Wilson & Hyde, 2013). It is therefore plausible, given the aforementioned adult studies into specific links between motor and social processes, that social changes over the course of adolescence and into adulthood may be associated, at least partly, with motor changes.

To our knowledge, perception of others' affective states across adolescence has not been widely researched. Most previous studies use facial stimuli, and show identification accuracy and sensitivity to emotion-specific signals continues to improve throughout adolescence (13 – 18 years old; Herba, Landau, Russell, Ecker, & Phillips, 2006; Johnston et al., 2011; Kolb, Wilson, & Taylor, 1992; Thomas, De Bellis, Graham, & LaBar, 2007). Despite body movements being an equally important emotional signal (de Gelder, 2006), the change in the perception of emotion from body movements has not been examined across adolescence[1]. Additionally, the potential use of own action models for perceptual processes has not been studied in this group.

The current study tests the hypothesis that emotion perception is linked with motor development in adolescence, by asking whether adolescents interpret affective states from movement cues differently from adults, and more precisely, in a way that would be predicted based on their own movement kinematics. Notably, from late childhood through to older age, one's 'spontaneous' speed of movement (McAuley, Jones, Holub, Johnston, & Miller, 2006) and 'preferred' walking pace (Froehle, Nahhas, Sherwood, & Duren, 2013; Oberg, Karsznia, & Oberg, 1993) has been shown to decrease. Therefore, if adolescents move with increased velocity relative to adults it is likely that they will make different judgments about others' internal states when these are based on velocity cues. This study could therefore contribute to the literature in two important ways. First, given the assumption that adolescents move differently, it will inform population-general theories about the links between action and emotion perception, as well as wider theories about associations between motor and social cognition processes. Second, it can help to inform our understanding of emotion perception in adolescence as a specific group – perhaps helping to explain the high number of conflicts between adults and adolescents, which may, in part, be related

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[1] Ross, Polson, & Grosbras (2012) included adolescents in their sample of children but had insufficient power to compare effects across this developmental period.

to misidentification of each others' emotional signals (Flannery, Montemayor, Eberly, & Torquati, 1993; Laursen, Coy, & Collins, 1998).

Specifically, it has been demonstrated that adults who typically move at a faster pace – and therefore are assumed to move particularly quickly when expressing anger but at a more similar speed to average when expressing sadness – rate angry (fast) stimuli as exhibiting less anger and sad (slow) stimuli as exhibiting more sadness, relative to participants who typically move more slowly (Edey et al. 2017). This pattern may reflect a mechanism whereby kinematic criteria used for emotional judgments are set relative to our own action experiences. For instance, we attribute anger when we perceive the velocity of others' actions to meet a threshold based on our own action experiences, rather than when velocity meets a universal threshold set similarly for all. By extension, we would expect differences in action velocity between adolescents and adults to generate corresponding differences in emotion perception. If typical movement velocity decreases across adolescence and into adulthood, adolescents may make incorrect inferences about an adult's expression of intense anger because the adult's angry (fast) movements do not reach the fast moving adolescent's criterion for an attribution of intense anger (see Figure 1).

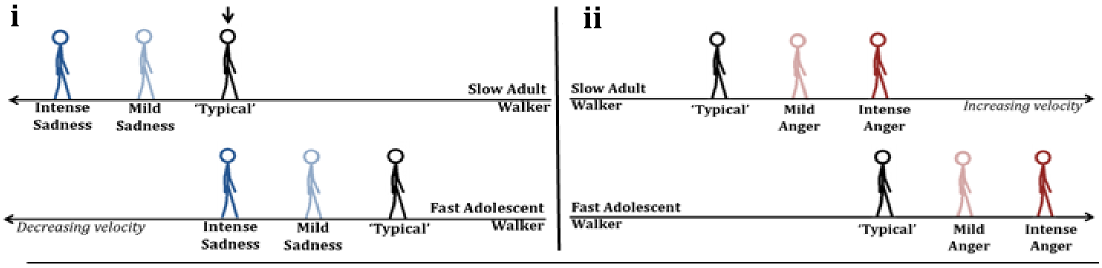

Figure 1: Schematic diagram of the hypothesis. The left panel (i) depicts the velocity of a 'slow' adult walker and a 'fast' adolescent walker when sad. The right panel (ii) depicts the velocity of a 'slow' adult walker and 'fast' adolescent walker when angry. Note that at the velocity highlighted by the arrow in the left panel, the slow adult is feeling no particular emotion, but a fast adolescent is feeling intense sadness. Therefore, the matched velocity of the two individuals are predicted to represent different internal states, which may affect their perception of each others' velocity signals.

Three groups of adolescents were tested (Early, Middle and Late Adolescence) and compared against an adult group. Participants viewed emotional (angry, happy or sad) point-light walker stimuli (PLW). These stimuli were chosen because they benefit from eliminating contextual cues, such as facial expressions, and allow for precise and controlled manipulation of kinematic cues whilst maintaining postural information, which were both critical for the current study. The velocity of these stimuli was either affect-specific (e.g., high velocity for angry walkers), or manipulated to converge to a neutral velocity (0, 33, 67 and 100% of the affect-specific velocity level, see Figure 2 and Supplementary Videos). Participants were asked to rate the extent to which the PLW appeared happy, angry or sad. In addition, participants' own typical walking velocity was recorded in an emotionally neutral context. We examined three questions. First, we asked whether adolescents use velocity cues to identify emotion, such that removal of affect-specific cues decreases the perceived intensity of the modelled emotion (see Figure 2A). Second, we measured action production velocity differences across adolescence and into adulthood. We predicted that velocity would decrease in a linear fashion across age groups, in line with the broad decrease seen previously from late childhood to old age.

Third, having ascertained that adolescents do use velocity cues, and that their action production velocity differed, we examined whether emotion perception varied across adolescence in a way that would be anticipated based upon their own movement velocity. Specifically, we hypothesized that the Early Adolescent group (fast movers) would rate the slower emotions (sadness) more intensely relative to the faster emotions (anger), and with increasing age (as their own movement speed decreased) the comparative difference in perceived intensity between the emotions would decrease or even reverse. Further regression analyses tested the hypothesis that own walking velocity would determine emotion perception to a greater extent than chronological age or puberty, *per se*. A number of developmental effects (e.g., Hulme, Thomson, & Muir, 1984; Peters, Koolschijn, Crone, Van Duijenvenvoorde, & Rajmakers, 2014) are driven by alterations in processes that change broadly across age, but that age itself is not the primary driver of the change. In this vein, we predicted in this study that perceptual differences would be driven by action production changes, seen broadly to change across age, rather than age itself. In other words, action production will broadly alter as adolescents get older, but at different ages for different adolescents, and it will be the action production rather than age itself that affects emotion perception.

2. Methods

2.1. Participants

All procedures received local ethical approval. Adolescent participants were recruited from two schools (both were state funded mixed secondary schools [11-16 years] with attached sixth-form colleges [16-19 years]). We recruited from three distinct school classes in the UK system – Year 7 (11-12), Year 9 (13-14) and Year 12 (16-18 years old). These classes were chosen to be approximately representative of distinct stages of adolescent development (Early, Middle and Late Adolescence; Spear, 2000). We invited 40 randomly selected adolescents from each age range (20 of each gender) to participate in the study and tested all who self-consented, and – for those under 16 years old – who obtained consent from their legal guardian. This method of opportunity sampling successfully met our objective of obtaining a minimum of 30 participants in each group, such that we would have at least 80% power to detect medium-sized (f=.25, alpha=.05) group, and group x condition interaction effects. These three groups of adolescents were compared against the data from an adult group ([aged 20-62 years] reported in Edey et al., 2017[2]; see Table 1). There was no difference in the ratio of male to female participants across the four groups ($\chi^2(3)=3.95$, $p=.267$). To confirm that gender did not contribute to any of the effects found, gender was

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[2] Please note that one adult was excluded from the sample reported in the current experiment because they were 18-years-old, while they were included in the original adult sample (Edey et al., 2017) as they were recruited through the same means as the other adults (i.e., through the local university database).

added as a fixed factor in each of the analyses reported below and no interactions with gender were found.

Table 1: Demographic data for the three adolescence and adulthood groups

	N	Gender (N and % male)	Age (years) Mean (SEM)
Early Adolescence	35	19 (54%)	11.83 (0.06)
Middle Adolescence	30	9 (30%)	13.90 (0.06)
Late Adolescence	30	13 (33%)	16.67 (0.10)
Adulthood	86	39 (53%)	29.62 (1.00)

2.2. Stimuli

The stimuli were PLWs adapted from those developed by Alaerts, Nackaerts, Meyns, Swinnen, & Wenderoth (2011). The original stimuli were filmed at two different viewpoints (coronal [0°] and intermediate to coronal and sagittal [45°]) while instructing a male and female actor to walk in happy, sad, angry or neutral affective states (see Alaerts et al., 2011, for further information[3]). Stimuli were ~21° visual angle vertically, and ~8–17° horizontally, when viewed at the typical distance of 40 cm.

Velocity-adapted stimuli were generated from the original PLWs to examine whether the adolescent groups used the velocity information in the same way as adults to make their emotional judgments. We generated three velocity-adapted

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[3] The current study only used the walking animations from Alaerts et al. (2011), such that we could establish correspondence with respect to production kinematics easily.

stimuli corresponding to each original emotional stimulus, by manipulating the velocity of the original videos (Figure 2A). The 0% stimuli exhibited a mean velocity equal to the mean velocity of the corresponding neutral stimulus (i.e., the velocity of the neutral male coronal stimulus was equal to that of the 0% happy male coronal stimulus), and 33% and 67% stimuli exhibited velocities between the neutral and 100% (i.e. original) emotional stimuli. These manipulations resulted in 48 emotion stimuli (3 emotions x 4 velocity-adaptations x 2 actors x 2 viewpoints).

Two random frames from each neutral walker frame-set were also selected, providing eight static control images which contained no emotional information – postures were neutral and there was no velocity information. These images were intended to control for overall response biases in participants, while noting that typical controls for PLWs (e.g., scrambled motion or inverted figures) would not achieve such an aim as they contain many of the same kinematic cues.

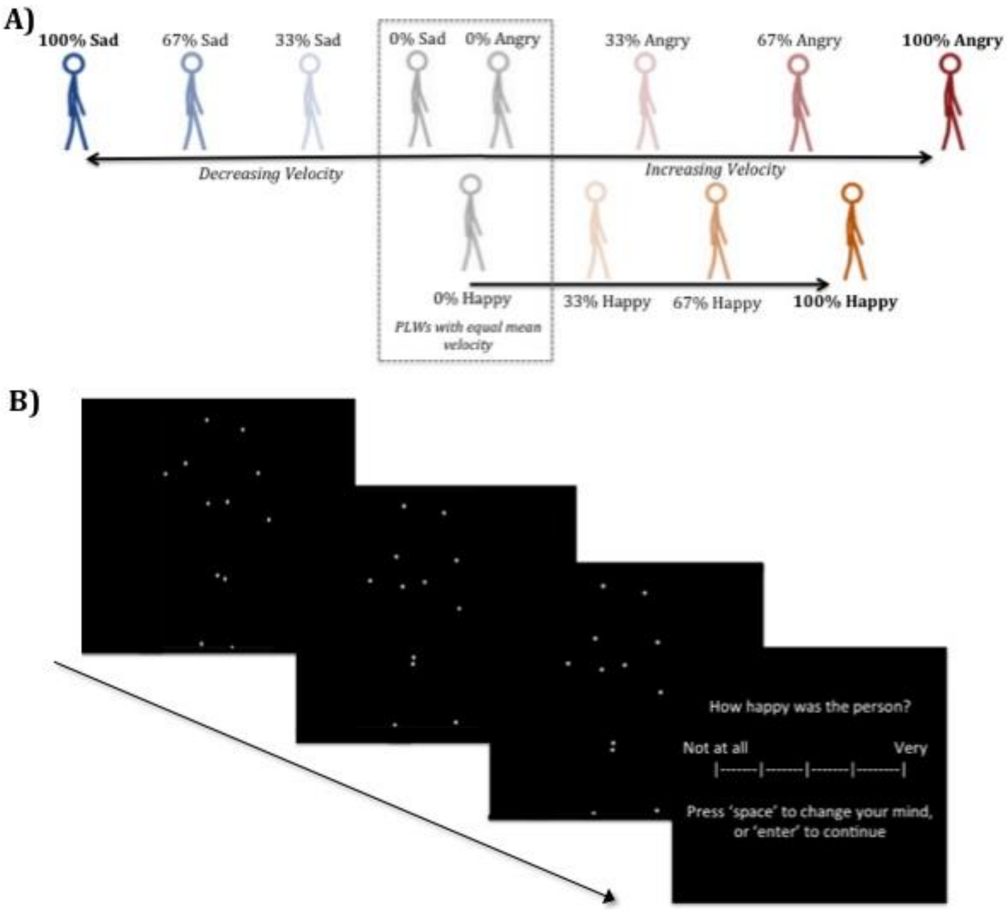

Figure 2: (A) The velocity of the original (100%) animations was altered to assess the extent to which velocity information is used to make affective state judgments. 0% stimuli exhibited velocities equal to the neutral stimuli (e.g. the 0% happy male coronal velocity was equal to that in the neutral male coronal animation), and 33% and 67% animations exhibited velocities between the neutral and 100% emotion stimuli. (B) Schematic of a trial. Participants were shown the point-light display once and were then asked to rate the extent to which the walker was happy, angry or sad by clicking with a mouse on an analogue scale. Participants then pressed a button to continue to the next trial.

2.3. Procedure

All participants first completed the emotion perception tasks with the original PLWs (100%), then the velocity adapted PLWs (67%, 33%, and 0% animations), and finally the static control images. Participants subsequently performed the walking task and completed the questionnaire measures [4]. The emotion perception tasks were run via Matlab® on a 24 inch screen computer, and were completed in a quiet room with the lights turned off at the adolescent participants' school during a lesson in the school day, and adults were tested in a psychology lab at the university. The whole experiment lasted approximately 50 minutes.

2.3.1. Emotion perception tasks

On each trial, the participants were presented with a PLW, and were asked to rate the extent to which the walker was happy, angry or sad (Figure 2B). The animation was only displayed once. Ratings were made by clicking with the mouse on a visual analogue scale ranging from 'not at all [happy, angry, sad]' to 'very [happy, angry, sad]'. Responses were recorded between 0 and 10, to two decimal places (note that no numerical values were presented to the participants). The initial position of the cursor was randomized for each trial. Participants could change their response until they pressed a key to continue. The emotional judgments to be made were blocked, resulting in three separate blocks (happy, angry and sad judgments), and all stimuli were presented in a random order once per block, thus all animations were rated for all three emotions. The order of the blocks was counterbalanced across all participants. Before beginning the study the

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[4] A fixed order was selected to enable comparability between the testing conditions for all participants and allow the study of individual differences. It was deemed that the walking task should always be performed after the emotion perception tasks to minimize the risk that participants were primed to make explicit reference to their own walking pace during the perception tasks. A biasing influence of the emotion perception task on the walking task was deemed less likely, given participants saw all emotions equally often before performance of the walking task (and noting that the emotion perception scores are all relative).

participants had three practice trials with 100% emotional sagittal PLWs, one for each emotion.

The procedure was the same when viewing the static control images. On each trial within each of the three blocks, one of eight images was presented for 2.04 seconds (the mean duration of all animations) and participants rated the emotion of these stimuli. These stimuli were used to measure response bias (see Control measures 3.4.1 and Supplementary Materials).

2.3.2. Walking task and questionnaires

Participants were asked to walk continuously between two cones (10 meters apart) at their own typical walking pace and informed they would be told when to stop (after 120 seconds). An iPhone 5c attached to the medial side of the participants' right ankle was used to track the precise time taken, and distance travelled for each participant, via the Sensor Kinetics Pro© application. The mean velocity for each participant was calculated as the distance traveled divided by the time taken (see Supplementary Materials for details on data pre-processing). The 'walkway' was an isolated corridor in the school (or university for adult participants) or the playground when the corridor was busy.

Participants additionally completed a state-mood questionnaire, where they rated on similar scales to those in the emotion perception tasks how happy, angry and sad they felt during the experiment, from 'not at all (happy, angry, sad)' to ' very (happy, angry, sad)'.

Puberty typically occurs between 11 and 16 years of age (Tanner et al., 1966). It is therefore often informative to dissociate age and puberty when examining social and cognitive processes throughout adolescence, given the impact of puberty on these processes (e.g., mentalizing, emotional regulation, and physical growth, see Blakemore & Choudhury, 2006). To this end, adolescent participants were also asked to identify their stage of pubertal growth using a puberty self-report question adapted from Petersen, Crockett, Richards, and Boxer (1988; see Supplementary Materials).

2.3 Analysis Methods

We calculated a number of measures from these tasks to test our hypotheses, in the same way that they were calculated in our adult study (Edey et al., 2017; see 'emotional intensity score' and 'emotional intensity beta score'). We also outline these methods in the appropriate Results sections below. We applied Greenhouse-Geisser corrections where necessary and Bonferroni corrected all multiple comparisons within and between groups.

2.4. Control measure analyses

Results from the static control ratings revealed a 'happy response bias' in the Middle and Late Adolescence and Adulthood groups, where participants gave higher ratings on the happy scale, relative to the angry and sad scales (see Supplementary Materials for full analysis). However, the Early Adolescence group exhibited no such bias. To account for any variance in emotion perception scores between the groups that is attributable to differences in response bias the main emotion perception analyses were therefore also conducted with the 'happy response bias' scores (happy static ratings – mean[sad and angry static ratings]) added as a covariate.

The state-mood analysis revealed no group differences, but a 'happy mood bias' was observed across all participants (see Supplementary Materials for full analysis). A 'happy mood bias' score was calculated (happy mood rating – mean[sad and angry mood ratings]) and again, the emotion perception analyses were repeated with this measure added as a covariate to ensure the effects found were not related to participants' mood.

3. Results

To summarise, as predicted, there was a linear decline in walking velocity across the age groups. Analysis of the perception data showed that all groups used the velocity information within the stimuli to determine emotions, such that reducing the velocity information within the PLWs attenuated the perceived intensity of the displayed emotion similarly across all groups. Most importantly, and also as predicted, measures comparing intensity ratings of different emotions also differed across adolescent development, such that with increasing age – i.e., as own production velocity decreased – the slow emotions were rated as less intense relative to the fast emotions. Finally, regression analyses demonstrated that emotion perception was predicted by own movement velocity, rather than age or pubertal stage *per se*.

3.1. Walking velocity analysis

Velocity data was lost due to technical error for 1 Late, 4 Middle, and 8 Early adolescent participants, resulting in N=29 Late, N=26 Middle and N=27 Early participants in the analysis. To test for linear effects of walking pace across the groups a one-way ANOVA was conducted comparing mean walking velocity across all four age groups, as measured by distance traversed across time. This analysis identified a linear trend across age group ($F(1, 164)=28.36$, $p<.001$). In line with our prediction, the direction of the linear trend was such that with increasing age walking velocity decreased.

The element of velocity which differs to the greatest extent between emotions is the speed at which the limbs move, and the raw velocity measure described above – i.e., distance over time – does not fully capture this variable. Specifically, a shorter participant will move their legs at a faster velocity to traverse the same distance as a taller participant in the given time and our participants differed substantially in height (141-191 cm). To account for this variance, we corrected the velocity measure by dividing the raw velocity measure by their height. Height data was unavailable for 50 Adults, 12 Late, 2 Middle and 1 Early Adolescent participants, so we used the series mean correction in these cases (i.e., effectively not correcting these velocity values by using the mean value for the group). Using these corrected velocity values reflected the same linear trend across age as presented above ($F(1,164)=64.57$, $p<.001$, see Figure 3A; note the same effect was also found when excluding participants for whom we did not have height data: $F(1,101)=51.60$, $p<.001$).

3.2. Group differences in emotion perception

3.2.2. Influences of velocity manipulations on emotion perception

We examined whether the adolescent groups used the velocity stimulus information, calculating ‘emotional intensity scores’ (EIS) for each emotion and velocity level (3 emotions x 4 levels). These measures were calculated as the mean rating on the modeled emotion scale minus the mean of the two ratings on the non-modeled emotion scales (e.g., Angry 100% - mean[Sad 100%, Happy 100%]); this subtraction was performed to calculate a measure akin to the precision of participants’ emotional representations). High EIS scores indicate that participants judged the PLW as intensely expressing the modelled emotion. Low (or negative) scores indicate that the PLW is judged as weakly expressing the modeled emotion or expressing a non-modeled emotion.

A mixed 3 (emotion - happy, angry and sad) x 4 (velocity level – 100%, 67%, 33%, and 0%) x 3 (Early, Middle, Late Adolescence, and Adulthood) ANOVA was performed (with emotion and velocity level as within-participant factors, and age group as a between-participant factor). We were specifically interested in linear trends across velocity level, or interactions with these, which would demonstrate the extent to which the groups used the velocity information to make their emotion judgments. As expected there was a linear trend across the four velocity levels ($F(1,177)=548.38$, $p<.001$, $\eta_p^2=.756$), which importantly showed no linear interaction with age group ($F(3,177)=1.00$, $p=.392$, $\eta_p^2=.017$; Figure 3B; note that linear effects across level were also found when analysing each age group independently, all *F*s>101.25, all *p*s<.001). There was a linear interaction between level and emotion ($F(1,177)=12.73$, $p<.001$, $\eta_p^2=.067$), but notably no three-way interaction between this effect and age group ($F(3,177)=1.49$, $p=.219$, $\eta_p^2=.025$, see Supplementary Materials for full results). The lack of three-way interaction between emotion, level and age group suggests that all groups used the velocity information differentially between emotions in a similar manner. Follow-up analysis for each individual emotion showed that there were significant linear effects across the velocity levels for all emotions (Sad: $F(1, 180)=391.71$, $p<.001$, $\eta_p^2=.685$; Happy: $F(1, 180)=72.97$, $p<.001$, $\eta_p^2=.288$; Angry: $F(1, 180)=128.29$, $p<.001$, $\eta_p^2=.416$), but the effect was strongest for the two emotions that are most reliably associated with velocity cues (sad and angry, e.g., Barliya et al., 2013; see Supplementary Figure 1).

A control analysis which included the 'happy rating bias' measured from the static control task and the 'happy mood bias' from the state-mood measure as covariates, revealed the same results. The linear trend across levels remained significant ($F(1,173)=136.761$, $p<.001$, $\eta_p^2=.442$), and the linear interaction with age group was non-significant ($F(3,173)=1.04$, $p=.377$, $\eta_p^2=.018$). Therefore differences in scale use or mood could not account for the effects found.

These results demonstrate that all age groups used the velocity cues to identify the modeled emotion, such that the perceived intensity of the emotion reduced as the velocity signal decreased.

3.2.3 Analysis of composite emotion perception scores

From the EIS we calculated composite emotional intensity beta scores (EIBS). The EIBS represent the linear relationship in intensity scores from the slowest (sad) to the fastest (angry) emotions (via happy). This score was calculated by modeling the regression slope (β) between animation velocity and EIS, such that the predictor values were the mean velocity of the PLWs' right ankle[5] for each of the three modeled emotions in the 100% emotion stimuli, and the dependent values were the corresponding EIS. A positive score denotes higher intensity ratings for the faster relative to the slower emotions and a negative score represents higher intensity ratings for the slower emotions (with more negative scores reflecting a larger discrepancy). This EIBS measure therefore represented, in a single value, the extent to which participants rated the 'fast' or 'slow' emotions more intensely whilst also standardizing the three emotional ratings across participants, accounting for individual differences in how participants used the scales (i.e., participants who hovered in the middle vs. those who used the full scale).

It was predicted that the EIBS would follow an opposite linear trend across age groups to that found for walking velocity. Specifically, the fastest group (Early Adolescence) were predicted to have the lowest EIBS and the scores were expected to increase as the groups got older (slower). To test this prediction a one-way ANOVA was performed across age groups. Critically and in line with predictions, there was a linear trend across age group that followed the predicted trajectory ($F(1,177)=4.84$, $p=.029$, see Figure 3B). Identical linear effects were found when controlling for 'happy mood bias' and 'happy response bias' (r=-.095, N=179, $p=.046$, 95% CI [-.185, -.004]). This pattern of results shows that the

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[5] The dot corresponding to the right ankle was chosen because it was the most comparable to the mean translational velocity measure obtained from participants using data from an iPhone attached to the participants' right ankle.

fastest movement group (Early Adolescence) rated the slow emotions as more e intense relative to the fast emotions and this relationship decrease across age.

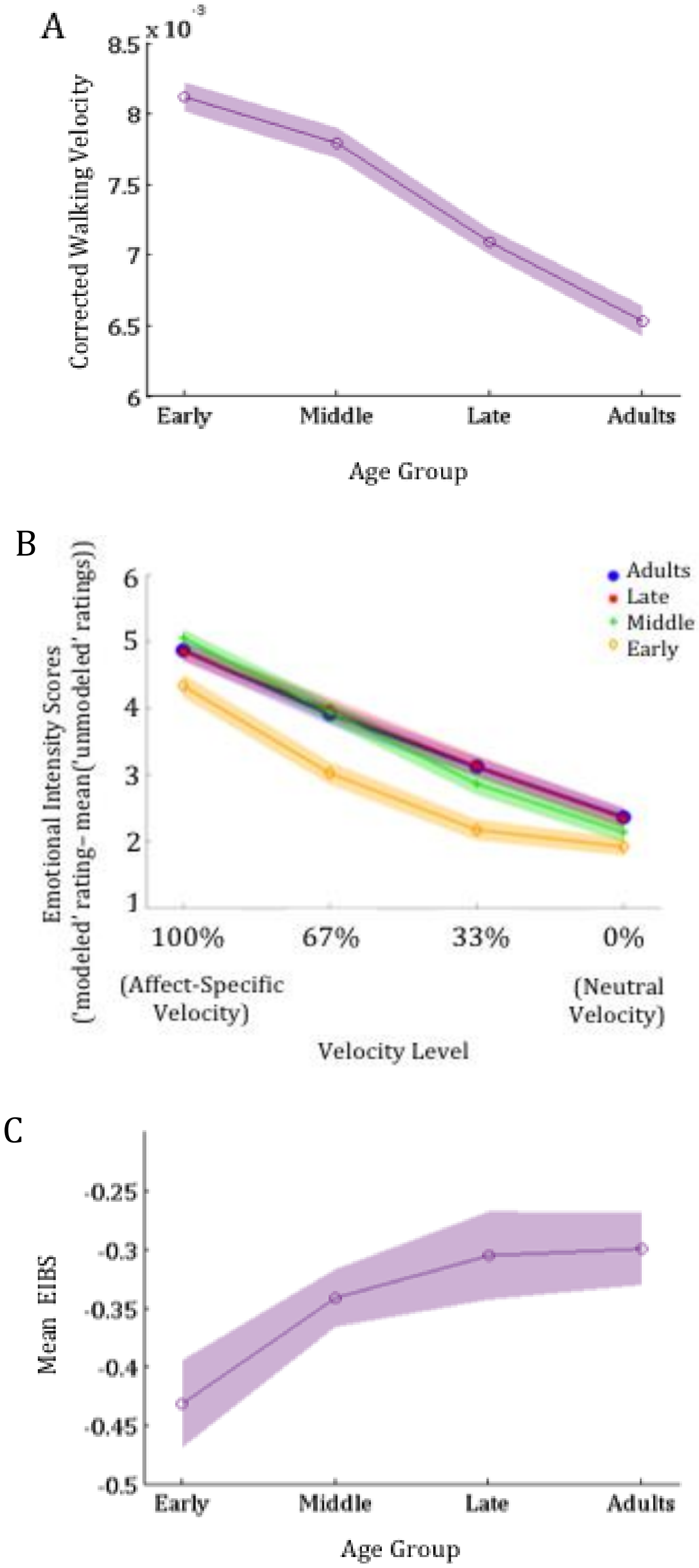

Figure 3: A) Mean walking velocity demonstrating the linear decrease across age groups. B) EIS across the four velocity levels demonstrating that all age groups used the velocity cues similarly. C) EIBS showing the predicted positive linear trend across age groups. A low EIBS represents participants rating the slower emotions (sad) as more intense relative to the faster emotions (anger).

3.3. Regression analysis

A multiple linear regression analysis was conducted to examine more specifically the factors that determine emotion perception across all adolescent and adult participants for whom we had velocity data. This analysis examined whether it was the walking velocity differences that determine the EIBS, or rather chronological age (note that although our hypotheses were based upon there being a relationship between these variables, importantly there was sufficient independent variance for these analyses to be informative; see 'tolerance' values in Table 2). The predictors entered into the model were therefore corrected movement velocity, chronological age (in years), and 'happy mood bias' and 'happy response bias'. All the predictors were entered into the model in a single step and significant predictors from this analysis ($p<0.05$) were subsequently included in the final model. As can be seen from Table 2, the only significant predictor of the EIBS was movement velocity (velocity only model: $F(1, 166)=13.70$, $p<.001$, $\beta=-.276$, $R^2= .07$; model including all predictors: $F(1, 166)=3.65$, $p=.007$, $R^2= .06$; see Figure 4). A similar multiple regression analysis with only adolescent participants, but also including pubertal development question score, similarly found that movement velocity was the only significant predictor (see Table 2; velocity only model: $\mathrm{F}(1, 81)=4.75$, $p=.032$, $\beta=-.237$, $\mathrm{R}^2= .06$; model including all predictors: $F(1, 81)=1.50$, $p=.199$, $R^2= .03$).

Therefore, this analysis demonstrates that the factor determining developmental differences in emotion perception was walking velocity, rather than age or puberty stage *per se*. Therefore, in line with predictions, this developmental difference in emotion perception appears to be driven by alterations in action production processes that change broadly across age, but the changes in this process drive the development rather than age itself.

Table 2: Results from the multiple linear regression analysis with all predictors included

Model	**Predictor**	**Beta**	***P***	***Tolerance***
All participants (N=167)				
Full model	**Movement velocity**	**-.301**	**<.001**	**.791**
	Happy response bias	.056	.461	.981
	Happy mood bias	.016	.830	.975
	Age	-.059	.489	.784
Adolescent participants only (N=82)				
Full model	**Movement velocity**	**-.260**	**.038**	**.783**
	Happy response bias	.135	.247	.892
	Happy mood bias	.018	.874	.957
	Age	-.109	.438	.560
	Puberty stage	.137	.292	.714

NB. Tolerance values >0.2 suggest sufficient independent variance and no multicollinearity problem (Field, 2009)

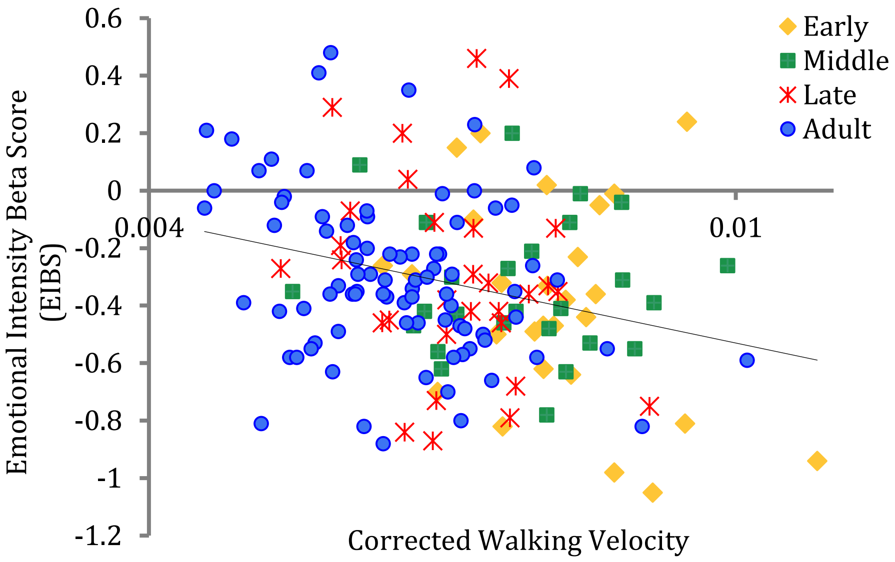

Figure 4: Scatterplot showing the negative correlation between the EIBS and the participants' own walking velocity.

4. Discussion

The present study asked whether emotion perception is linked to motor development across adolescence. To this end we examined whether developmental differences in action velocity were associated with differences in emotion perception from velocity cues. Analysis of the perception data demonstrated that adolescents, like adults, used the velocity information within the stimuli to determine emotions, such that reducing the velocity information within the PLWs attenuated the perceived intensity of the displayed emotion similarly across all groups. There was also a linear decline in walking velocity across the age groups, in line with previous literature suggestive of a decrease in velocity from late childhood to older age (Froehle et al., 2013; McAuley et al., 2006; Oberg et al., 1993) and clarifying that this change is found across the specific adolescent development period. Importantly, and as predicted, measures comparing intensity ratings of different emotions also differed across adolescent development, such that with increasing age – i.e., as own production velocity decreased – the slow emotions were rated as less intense relative to the fast emotions. A multiple regression analysis revealed that it was movement velocity itself that predicted emotion perception across participants, rather than chronological age or puberty stage *per se*. These results suggest that the age-related differences in emotion perception were likely determined by differences in movement velocity that change across development.

While overall movement velocity is only one of many different possible kinematic cues to another's emotional state – which could account for the low, but significant, variance explained in the regression analysis – the present findings provide novel evidence that adolescents calibrate their evaluation of others' internal states to models of their own action experiences. It is assumed that this 'own action tuning' emerges because observation of others' movements activates codes involved in moving with those kinematics oneself (motoric and perceptual codes; see Press & Cook, 2015; Peelen & Downing, 2007). Internal state attribution is thus determined according to associations between internal states and these codes, and internal states are perhaps assigned to others once a certain threshold criterion in kinematics is met (Edey et al., 2017). Understanding of others is hence hypothesized to be most accurate when their actions are similarly calibrated to our own. Such tuning may have implications for understanding of and communication with populations who move with atypical kinematics across the lifespan, for example those with developmental disorders such as autism spectrum disorders or Tourette Syndrome (Eddy & Cavanna, 2015; Edey et al., 2016) or neurodegenerative disorders, such as Huntington's Disease (Eddy & Rickards, 2015).

The present findings demonstrate how such 'own action tuning' can also have implications for social cognition and communication between typically developing individuals at different stages of development. Specifically, given this predicted mechanism of own action calibration, and that adolescents move differently from adults, the current findings suggest that adolescents might frequently misrepresent adults' expressed internal states. Moreover the current data similarly suggest that adults will be more likely to attribute erroneous affective states to adolescent actions, as they will be interpreted via an adult action model. For example, adolescents who are not expressing any strong emotion – but moving with their faster typical kinematics – may be perceived as angry by an adult observer, and expressions of sadness will more frequently go undetected. Misattributions of others' internal states due to differences in own action models could therefore be a contributing factor to the high number of conflicts between adults and adolescents (e.g., caregivers and children; Flannery et al., 1993; Laursen et al., 1998). Bidirectional attribution errors in how adults and adolescents recognize and respond to each other's internal states may also complicate emotional socialization (how adolescents learn to regulate and express their emotions according to feedback from others; Cracco, Goossens, & Braet, 2017; Halberstadt, 1986; Meyer, Raikes, Virmani, Waters, & Thompson, 2014; Sanders, Zeman, Poon, & Miller, 2015; Zeman, Cassano, & Adrian, 2013).

Similar predictions could be made about other internal states that are associated with specific kinematic signatures, as well as examining extension of the hypothesis to more subtle and complex kinematic signatures. For instance, the perception of others' confidence (Patel et al., 2012), competitiveness (Georgiou, et al., 2007) or trustworthiness (Krumhuber & Kappas, 2005) may be incorrectly attributed between adults and adolescents who move differently, given their reliance on kinematic cues. To explore fully the nature of communication difficulties between adolescents and adults, future work could therefore look to replicate the current experiment but using actions expressing other internal states, as well as adolescent actors to examine the bi-directionality of any attribution difficulties. Future work could also examine the extent to which our findings with mimed emotional actions are mirrored with naturalistic emotional actions. For example, while the majority of individuals may increase their velocity when angry, this velocity cue will be more subtle when induced by real internal states rather than instructions. Finally, it would be interesting to use measures in the future that can separate sensitivity to correctly displayed emotions from perceived intensity of those emotions, which are difficult to dissociate with the current measures.

Interestingly, the regression analysis indicated that it was not the age *per se* of participants that determined emotion perception scores, but rather walking velocity – which covaries with age. This is in line with our hypothesis that adolescents' emotion perception would differ from that of adults due to differences in the way they move, but that the mechanism for emotion perception – i.e., calibration according to own action experiences – operates similarly in adolescents and adults. Our understanding of the development of this mechanism could be increased further by adapting these paradigms for studies in younger children to ascertain whether action production and internal state perception are yoked throughout life, or whether the mechanism comes online at a specific developmental stage or following specific experiences (e.g., Gerson, Bekkering, & Hunnius, 2014).

In conclusion, these results demonstrate that across adolescence and into adulthood our preferred movement velocity decreases, and these differences in action production are accompanied by differences in emotion perception from velocity cues. These findings provide an example of how changes in action production across adolescence have implications for social and cognitive development.

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References

Ada, M. S., Suda, K., & Ishii, M. (2003). Expression of emotions in dance: relation between arm movement characteristics and emotion. *Perceptual and Motor Skills*, *97*(3), 697–708. https://doi.org/10.2466/pms.2003.97.3.697

Alaerts, K., Nackaerts, E., Meyns, P., Swinnen, S.P., & Wenderoth, N. (2012). Action and emotion recognition from point light displays: An investigation of gender differences. *PLoS ONE.* https://doi.org/10.1371/journal.pone.0020989

Assaiante, C. (2011). Building of action and representation of action during infancy, childhood and adolescence. *BIO Web of Conferences*, *1*, 00005. https://doi.org/10.1051/bioconf/20110100005

Atkinson, A. P., Dittrich, W. H., Gemmell, A. J., & Young, A. W. (2004). Emotion perception from dynamic and static body expressions in point-light and full-light displays. *Perception*, *33*(6), 717–746. https://doi.org/10.1068/p5096

Atkinson, A. P., Tunstall, M. L., & Dittrich, W. H. (2007). Evidence for distinct contributions of form and motion information to the recognition of emotions from body gestures. *Cognition*, *104*(1), 59–72. https://doi.org/10.1016/j.cognition.2006.05.005

Barliya, A., Omlor, L., Giese, M. A., Berthoz, A., & Flash, T. (2013). Expression of emotion in the kinematics of locomotion. *Experimental Brain Research*, *225*(2), 159–176. https://doi.org/10.1007/s00221-012-3357-4

Becchio, C., Koul, A., Ansuini, C., Bertone, C., & Cavallo, A. (2018). Seeing mental states: An experimental strategy for measuring the observability of other minds. *Physics of Life Reviews, 24,* 67-80.

Blakemore, S.-J., & Choudhury, S. (2006). Development of the adolescent brain: implications for executive function and social cognition. *Journal of Child Psychology and Psychiatry*, *47*(3–4), 296–312. https://doi.org/10.1111/j.1469-7610.2006.01611.x

Brown, E. C., & Brüne, M. (2012). The role of prediction in social neuroscience. *Frontiers in Human Neuroscience*, *6*. https://doi.org/10.3389/fnhum.2012.00147

Cavallo, A., Koul, A., Ansuini, C., Capozzi, F., & Becchio, C. (2016). Decoding intentions from movement kinematics. *Scientific Reports*, *6*(1). https://doi.org/10.1038/srep37036

Cracco, E., Goossens, L., & Braet, C. (2017). Emotion regulation across childhood and adolescence: evidence for a maladaptive shift in adolescence. *European Child & Adolescent Psychiatry*, *26*(8), 909–921. https://doi.org/10.1007/s00787-017-0952-8

Davies, P. L., & Rose, J. D. (2000). Motor Skills of Typically Developing Adolescents: Awkwardness or Improvement? *Physical & Occupational Therapy In Pediatrics*, *20*(1), 19–42. https://doi.org/10.1080/J006v20n01_03

de Gelder, B. (2006). Towards the neurobiology of emotional body language. *Nature Reviews Neuroscience*, *7*(3), 242–9. https://doi.org/10.1038/nrn1872

Davies, P. L., & Rose, J. D. (2000). Motor Skills of Typically Developing Adolescents: Awkwardness or Improvement? *Physical & Occupational Therapy In Pediatrics*, *20*(1), 19–42. https://doi.org/10.1080/J006v20n01_03

Dumontheil, I. (2016). Adolescent brain development. *Current Opinion in Behavioral Sciences*, *10*, 39–44. https://doi.org/10.1016/j.cobeha.2016.04.012

Eddy, C. M., & Cavanna, A. E. (2015). Triangles, tricks and tics: Hyper-mentalizing in response to animated shapes in Tourette syndrome. *Cortex*, *71*, 68–75. https://doi.org/10.1016/j.cortex.2015.06.003

Eddy, C. M., & Rickards, H. E. (2015). Interaction without intent: the shape of the social world in Huntington's disease. *Social Cognitive and Affective Neuroscience*, *10*(9), 1228–1235. https://doi.org/10.1093/scan/nsv012

Edey, R., Cook, J., Brewer, R., Johnson, M. H., Bird, G., & Press, C. (2016). Interaction takes two: Typical adults exhibit mind-blindness towards those with autism spectrum disorder. *Journal of Abnormal Psychology*, *125,* 879-885.

Edey, R., Yon, D., Cook, J., Dumontheil, I., Press, C. (2017). Our own action kinematics predict the perceived affective states of others. *Journal of Experimental Psychology: Human Perception and performance.* 43(7): 1263-58. http://dx.doi.org/10.1037/xhp0000423

Field, A. P. (2009). Discovering statistics using SPSS. London, England: SAGE.

Flannery, D., Montemayor, R., Eberly, M., & Torquati, J. (1993). Unraveling the ties that bind: Affective expression and perceived conflict in parent-adolescent interactions. *Journal of Social and Interpersonal Relationships*, *10*, 495–509.

Froehle, A. W., Nahhas, R. W., Sherwood, R. J., & Duren, D. L. (2013). Age-related changes in spatiotemporal characteristics of gait accompany ongoing lower limb linear growth in late childhood and early adolescence. *Gait & Posture*, *38*(1), 14–19. https://doi.org/10.1016/j.gaitpost.2012.10.005

Georgiou, I., Becchio, C., Glover, S., & Castiello, U. (2007). Different action patterns for cooperative and competitive behaviour. *Cognition*, *102*(3), 415–433. https://doi.org/10.1016/j.cognition.2006.01.008

Gerson, S. A., Bekkering, H., & Hunnius, S. (2014). Short-term Motor Training, but Not Observational Training, Alters Neurocognitive Mechanisms of Action Processing in Infancy. *Journal of Cognitive Neuroscience*, 1–9. https://doi.org/10.1162/jocn_a_00774

Halberstadt, A. G. (1986). Family socialization of emotional expression and nonverbal communication styles and skills. *Journal of Personality and Social Psychology*, *51*(4), 827–836. https://doi.org/10.1037/0022-3514.51.4.827

Herba, C. M., Landau, S., Russell, T., Ecker, C., & Phillips, M. L. (2006). The development of emotion-processing in children: effects of age, emotion, and intensity. *Journal of Child Psychology and Psychiatry*, *47*(11), 1098–106. https://doi.org/10.1111/j.1469-7610.2006.01652.x

Hulme C, Thomson N, Muir C, L. A. (1984). Speech rate and the development of short-term memory span. *Journal of Experimental Child Psychology 1*, *38*, 241–253.

Johnson, M. H. (2011). Interactive specialization: a domain-general framework for human functional brain development? *Developmental Cognitive Neuroscience*, *1*(1), 7–21. https://doi.org/10.1016/j.dcn.2010.07.003

Kausche, C., Bahn, D., Vesker, M., & Schwarzer, G. (2019). The role of emotional valence for the processing of facial and verbal stimuli – positivity or negativity bias? Frontiers in Psychology, 10, 1654. https://doi.org/10.3389/fpsyg.2019.01654

Kenny, L., Hill, E., & Hamilton. A. (2016). The relationship between social and motor cognition in primary school age-children. *Frontiers in Psychology, 7.* https://doi.org/10.3389/fpsyg.2016.00228

Kolb, B., Wilson, B., & Taylor, L. (1992). Developmental changes in the recognition and comprehension of facial expression: Implications for frontal lobe function. *Brain and Cognition*, *20*(1), 74–84. https://doi.org/10.1016/0278-2626(92)90062-Q

Krumhuber, E., & Kappas, A. (2005). Moving Smiles: The Role of Dynamic Components for the Perception of the Genuineness of Smiles. *Journal of Nonverbal Behavior*, *29*(1), 3–24. https://doi.org/10.1007/s10919-004-0887-x

Largo, R. H., Caflisch, J. A., Hug, F., Muggli, K., Molnar, A. A., Molinari, L., … Gasser, T. (2001). Neuromotor development from 5 to 18 years. Part 1: timed performance. *Developmental Medicine & Child Neurology*, *43*(7), 436–443. https://doi.org/10.1111/j.1469-8749.2001.tb00739.x

Laursen, B., Coy, K. C., & Collins, W. A. (1998). Reconsidering Changes in Parent-Child Conflict across Adolescence: A Meta-Analysis. *Child Development*, *69*(3), 817–832. https://doi.org/10.1111/j.1467-8624.1998.tb06245.x

Leonard, H.C., & Hill, E.L. (2014). The impact of motor development on typical and atypical social cognition and language: A systematic review. *Child and Adolescent Mental Health, 19,* 163-170.

McAuley, J. D., Jones, M. R., Holub, S., Johnston, H. M., & Miller, N. S. (2006). The time of our lives: Life span development of timing and event tracking. *Journal of Experimental Psychology: General*, *135*(3), 348–367. https://doi.org/10.1037/0096-3445.135.3.348

Meyer, S., Raikes, H. A., Virmani, E. A., Waters, S., & Thompson, R. A. (2014). Parent emotion representations and the socialization of emotion regulation in the family. *International Journal of Behavioral Development*, *38*(2), 164–173. https://doi.org/10.1177/0165025413519014

Oberg, T., Karsznia, A., & Oberg, K. (1993). Basic gait parameters: reference data for normal subjects, 10-79 years of age. *Journal of Rehabilitation Research and Development*, *30*(2), 210–223.

Patel, D., Fleming, S. M., & Kilner, J. M. (2012). Inferring subjective states through the observation of actions. *Proceedings of the Royal Society B: Biological Sciences*, *279*(1748), 4853–4860. https://doi.org/10.1098/rspb.2012.1847

Peelen, M. V., & Downing, P. E. (2007). The neural basis of visual body perception. *Nature Reviews Neuroscience*, *8*(8), 636–648. https://doi.org/10.1038/nrn2195

Peters, S., Koolschijn, P. C. M. P., Crone, E. A., Van Duijvenvoorde, A. C. K., & Raijmakers, M. E. J. (2014). Strategies influence neural activity for feedback learning across child and adolescent development. *Neuropsychologia*, *62*, 365–374. http://doi.org/10.1016/j.neuropsychologia.2014.07.006

Petersen, A. C., Crockett, L., Richards, M., & Boxer, A. (1988). A self-report measure of pubertal status: Reliability, validity, and initial norms. *Journal of Youth and Adolescence*, *17*(2), 117–133. https://doi.org/10.1007/BF01537962

Press, C., & Cook, R. (2015). Beyond action-specific simulation: domain-general motor contributions to perception. *Trends in Cognitive Sciences*, *19*(4), 176–178. https://doi.org/10.1016/j.tics.2015.01.006

Quatman-Yates, C. C., Quatman, C. E., Meszaros, A. J., Paterno, M. V., & Hewett, T. E. (2012). A systematic review of sensorimotor function during adolescence: a developmental stage of increased motor awkwardness? *British Journal of Sports Medicine*, *46*(9), 649–655. https://doi.org/10.1136/bjsm.2010.079616

Roether, C. L., Omlor, L., Christensen, A., & Giese, M. A. (2009). Critical features for the perception of emotion from gait. *Journal of Vision*, *9*(6), 15–15. https://doi.org/10.1167/9.6.15

Roether, Claire L., Omlor, L., & Giese, M. A. (2009). Features in the Recognition of Emotions from Dynamic Bodily Expression. In U. J. Ilg & G. S. Masson (Eds.), *Dynamics of Visual Motion Processing* (pp. 313–340). Boston, MA: Springer US. Retrieved from http://link.springer.com/10.1007/978-1-4419-0781-3_14

Rogol, A. D., Clark, P. A., & Roemmich, J. N. (2000). Growth and pubertal development in children and adolescents: effects of diet and physical activity. *The American Journal of Clinical Nutrition*, *72*(2 Suppl), 521S–8S.

Rueckriegel, S. M., Blankenburg, F., Burghardt, R., Ehrlich, S., Henze, G., Mergl, R., & Hernáiz Driever, P. (2008). Influence of age and movement complexity on kinematic hand movement parameters in childhood and adolescence. *International Journal of Developmental Neuroscience*, *26*(7), 655–663. https://doi.org/10.1016/j.ijdevneu.2008.07.015

Sanders, W., Zeman, J., Poon, J., & Miller, R. (2015). Child Regulation of Negative Emotions and Depressive Symptoms: The Moderating Role of Parental Emotion Socialization. *Journal of Child and Family Studies*, *24*(2), 402–415. https://doi.org/10.1007/s10826-013-9850-y

Steinberg, L. (2005). Cognitive and affective development in adolescence. *Trends in Cognitive Sciences*, *9*(2), 69–74. https://doi.org/10.1016/j.tics.2004.12.005

Tanner, J. M., Whitehouse, R. H., & Takaishi, M. (1966). Standards from birth to maturity for height, weight, height velocity, and weight velocity: British children, 1965. II. *Archives of Disease in Childhood*, *41*(220), 613–635. https://doi.org/10.1136/adc.41.220.613

Thomas, L. A., De Bellis, M. D., Graham, R., & LaBar, K. S. (2007). Development of emotional facial recognition in late childhood and adolescence. *Developmental Science*, *10*(5), 547–58. https://doi.org/10.1111/j.1467-7687.2007.00614.x

Visser, J., Geuze, R. H., & Kalverboer, A. F. (1998). The relationship between physical growth, the level of activity and the development of motor skills in adolescence: Differences between children with DCD and controls. *Human Movement Science*, *17*(4–5), 573–608. https://doi.org/10.1016/S0167-9457(98)00014-1

Wang, M.V., Lekhal, R., Aarø, L.E., & Schjølberg, S. (2012). Co-occuring development of early childhood communication and motor skills: Results from a population-based longitudinal study. *Child: Care, Health and Development, 40,* 77-84.

Wilson, P. H., & Hyde, C. (2013). The development of rapid online control in children aged 6?12years: Reaching performance. *Human Movement Science*, *32*(5), 1138–1150. https://doi.org/10.1016/j.humov.2013.02.008

Zeman, J., Cassano, M., & Adrian, M. (2013). Socialization influences on children's and adolescent's emotional self-regulation processes: A developmental psychopathology perspective. In K. C. Barrett, N. A. Fox, G. A. Morgan, D. J. Fidler, & L. Daunhauer (Eds.), *Handbook of self-regulatory processes in development: New directions and international perspectives*. New York: Psychology Press.