Physical activity in infancy: developmental aspects, measurement, and importance

John Worobey

ABSTRACT
Relative to work on nutrient intake and growth in infancy and toddlerhood, research on physical activity (PA) from birth to age 24 mo is limited. In this review, the developmental course of PA in infancy and toddlerhood is described, and the issues that surround its measurement are addressed. Of the variety of techniques that allow for gauging PA in infancy and toddlerhood, caregiver questionnaires, direct observations, and motion sensors have been used most frequently. Although each method has shown utility, the limitations of each are also acknowledged. In addition, the relation of early PA to nutrition and overweight in infants is considered. Despite the challenges to accurately monitoring early PA, its possible contribution to early excess weight gain should be recognized. 

Am J Clin Nutr 2014;99(suppl):729S–33S.

INTRODUCTION
Physical activity (PA) has long been considered a core reflection of individual differences among infants, and as a dimension of behavior it is included in virtually all theoretical formulations of temperament (1). PA is evident as early as the newborn period (2), and is noteworthy for its saliency to most parents as well as for its demonstrated stability throughout early development (3). With the alarming increase in rates of childhood obesity, apparent now even before the age of 2 y (4), increased interest in PA and sedentary behavior during the first few years of childhood has been shown. A recent review of the available evidence concluded that objectively measured habitual PA is low and sedentary behavior is high among preschoolers, with levels far different from those that are recommended (5). Although little research on PA levels exists for the periods of infancy (0–12 mo) and toddlerhood (12–24 mo), a separate review of this scant literature suggests a similar pattern of limited activity and excessive sedentary behavior (6). In the present review, the developmental course of activity in infancy and toddlerhood will be described, and the issues that surround its measurement will be addressed. In addition, the relation of early PA to nutrition and overweight in infants will be considered.

THE COURSE OF PA
PA in the first 12 mo of postpartum life is expressed through what Thelen (7) terms rhythmical stereotypies, fundamentally gross motor movements that seem to lack any observable goal or purpose. The age ranges specified here are approximate and are subject to individual differences; nevertheless, the earliest movements are typically arm waving (from the first weeks onward) and leg kicking (2–5 mo). When placed in a seated position, infants might rock back and forth, sway side to side, or bounce up and down (5–10 mo). Scooting may also be seen, in which the infant pushes with the feet in a sitting position and moves backward. In pulling themselves to stand, bouncing, swaying, or pushing backward and forward may also be observed, but such behaviors are now apparent in an upright position (6–11 mo). The waving of one or both arms, or banging if an object is held, continues throughout the first year and peaks near its end (8–11 mo).

Crawling with his or her belly on the floor (4–8 mo) usually precedes creeping, where the infant is in a quadruped (hand-knee) position (7–11 mo), and both of these types of actions allow for locomotion. With standing more frequent, the infant likely exhibits cruising, by holding on to an edge of furniture and moving the feet sideways to travel restricted distances (7–13 mo). Standing unassisted by the end of the first year is the prerequisite for walking (11–14 mo), although the infant may still choose to creep if early walking efforts are a bit unsteady (hence the term “toddler”). Over the next few months walking becomes more polished, with the feet widely spaced but the gait appearing somewhat more regular. During the second year the space between the feet gradually narrows and the feet begin to point straight ahead. At 18 mo, walking in a hurry almost resembles running and can allow the toddler to move as fast as 5–6 feet/s (8). By age 2 y, the toddler’s gait looks increasingly rhythmical, with as many 170 steps taken per minute (9).

As one would expect, with the dramatic increase in motor control and ability over the first 2 postpartum years, infants have a greater opportunity to be physically active of their own volition.
Regardless of the approach used in its measurement (see Measurement of PA), activity levels reliably increase over the first year as evidenced from a number of longitudinal and cross-sectional studies. This is apparent whether infants are observed by trained home visitors (10), in standardized laboratory tasks (11), or with motion sensors (12). If relying on caregiver ratings in everyday contexts, a pronounced pattern of incremental increases in mean activity levels has been shown from 2 wk through 24 mo (10, 13–15). Despite the steady increase in activity level that is evident across studies, within-subject stability is nevertheless present over the first 2 y (16).

With regard to sex differences in activity level, the results of 2 meta-analyses conducted on 14 studies (17) and 46 studies (18), respectively, suggest that even as infants, boys are motorically more active than girls when assessed with objective measurement tools. Interestingly enough, studies that used caregiver ratings have traditionally failed to show sex differences (10, 15, 19). However, more recent work has shown caregiver ratings of infants to support the finding that boys are more active (20).

**MEASUREMENT OF PA**

A variety of approaches exist for measuring children's PA, which range from the behavioral to the physiologic (21). Whereas behaviorists characterize activity according to its type and the context in which it is displayed, physiologists characterize PA in terms of energy expended, usually in calories or megajoules, and consider the intensity and length of time of the activity (22). A number of sophisticated methods are now available to measure energy expenditure as early as infancy with greater precision. However, the prohibitive expense of the doubly labeled water method (23), or requiring the subject's confinement as in indirect calorimetry (24), renders these techniques impractical for population studies. For this reason the approaches reviewed next will be confined to questionnaires, observations, and motion sensors.

**Questionnaires**

A variety of questionnaires, surveys, and interview scripts are available to rate and thereby describe early temperament (3, 25). The instruments inspired by 3 different theoretical camps have generated the most interest, with each group having their own versions of questionnaires. Relevant to our present purposes, each of them includes a specific activity dimension. The Carey scales derive from a clinician’s perspective and were among the first questionnaires to be used for gauging temperament (26–29). Alternately, the Plomin instruments are personality-driven and their measurement approach is much more global (30, 31).

In contrast, the Rothbart questionnaires are psychobiological in their conception and have generated the most research (13, 20, 32). Indeed, the work cited above (10, 14, 15) that showed the steady increase in ratings of activity over time used the Rothbart (32) Infant Behavior Questionnaire (IBQ). Responses to a set of questions, arranged by situation or context, are answered by the caregiver on scale of “never” to “always” (eg, “During sleep, how often did the baby toss about in the crib?”). The IBQ (20, 32) asks the caregiver to consider the infant’s behavior over the course of the preceding week, whereas the toddler version (13) asks about the preceding 2 wk.

As another example, a recent study relied on parental interviews to estimate time spent in low-to-vigorous activity by toddlers aged 12–24 mo. By using a structured questionnaire (which had been validated with parents of 6-y-olds), the author reported that the boys spent 1.45 h/wk in light-to-vigorous physical activity (L-VPA) compared with the girls who spent 1.05 h/wk, which represented a nonsignificant difference by sex (33). The author defined L-VPA as outdoor activities that caused heavy breathing and lasted at least 20 min. These results would suggest that children spent only ~9–13 min/d engaged in light to vigorous activity. However, the value of assessing L-VPA in 1- to 2-y-olds via parental report remains understudied.

**Observations**

Unlike the bulk of studies that have tapped activity as a dimension of temperament by using questionnaires, relatively few studies have examined activity in infancy or toddlerhood with the use of observational methods, and the few studies that exist have used different behavioral coding systems. Rothbart (10) had trained coders observe infants and mothers in their homes, checking off precoded behaviors at 15-s intervals for 30–45 min over 3 d at 3, 6, and 9 mo. After the visits, frequencies of behaviors were weighted taking both intensity and frequency into account. For example, an infant moving all 4 limbs at the same time was given twice the weight of moving 2 limbs. Similar to the IBQ results, mean levels of activity were found to increase across the 3 ages. Although the ratings and observations of activity did not correlate at 3 mo, convergence was shown at 6 and 9 mo (10). Carnicero et al (11) sought to measure agreement over the first year between maternal ratings and infant behavior elicited via a series of prescribed activities in a laboratory setting, a procedure developed by Matheny and Wilson (34). At 3, 6, and 9 mo, the IBQ ratings of activity did not correlate with the laboratory activity scores. At 12 mo, however, the correlation between measures was significant; but interestingly, activity had been rated by mothers with the use of a questionnaire developed by Goldsmith (35) for children aged ≥12 mo instead of the IBQ.

With a cohort of 12-mo-old twins, Wilson and Matheny (36) videotaped the infants’ behavior with the use of the laboratory procedures they previously validated (34). Behavior was subsequently coded over successive 2-min epochs for the hour-long observation, along with rating the infants’ behavior while having anthropometric measurements taken. Yet, no significant correlations were found for either the observed or rated activity level with activity as scored by mothers by using the Carey toddler questionnaire (28). Also using a laboratory setting, Goldsmith and Rothbart (37) coded toy manipulation and locomotion by 18-mo-old toddlers during 5 min of free play—1 of 4 activity-eliciting episodes from the Laboratory-TAB procedure (38). In the authors’ words, they “did not observe good convergence” (authors’ italics, p 268) with the activity scale of the Goldsmith (35) questionnaire. They attributed this failure to contamination of the maternal ratings due to the pleasure-related content in the items that measured temperament as displayed during toy play.

To estimate time spent in various levels of activity in child care centers shown by 2-y-olds, Gubbels et al (39) used the Observational System for Recording Physical Activity in Children–Preschool Version (OSRAC-P), an instrument previously validated in 3- to 5-y-old children (40). As might be expected,
a higher proportion of moderate and vigorous activity was seen outdoors (21.3%) than indoors (5.5%).

**Motion sensors**

In recent years, accelerometers have become popular as a tool for objectively assessing PA in childhood (21, 22). These devices measure the frequency and magnitude of the body’s acceleration when moving and are small enough to be worn by infants. Long before the availability of today’s accelerometers, actometers—modified wristwatches that measure movement in 2 planes—were used to measure early activity. For example, Eaton and his colleagues were among the first to attempt to show convergence between actometer-measured activity and maternal ratings of the same. With 3-mo-old infants agreement was not achieved (41); however, with 7-mo-olds their correlation between the actometers and IBQ activity ratings was significant (42). More recent efforts with accelerometers have shown somewhat similar results; that is, whereas convergence between the measures is not shown at 3 mo, it becomes apparent by 6 mo (43).

The lack of agreement at 3 mo may be attributable to the mother’s evolving recognition of her infant’s individuality, or if a primipara, to her not having a frame of reference for what constitutes a normal level of activity. But a more obvious factor may be the confounding of infant activity with the mother’s lifting and carrying of her infant that is registered by the accelerometer. Indeed, some 40–50% of the measured activity in infants this young may be attributed to the caregiver’s necessary handling of the infant (44, 45). As the infant begins to walk, infants this young may be attributed to the caregiver’s necessary handling of the infant (44, 45). As the infant begins to walk, it should theoretically become easier to isolate infant movements during extended periods of observation; hence, stronger associations would be expected with increasing age.

A pilot study in nine 4- to 17-mo-olds shows this uncertainty (46). Diary activity data were grouped by the investigators into sleeping/eating, quiet play, and active play. Each infant’s accelerometer data were split into tertiles of low, moderate, and high and categorized as sedentary/light, moderate, and vigorous activity, respectively. Even though the researchers found a positive relation between caregiver diary entries and accelerometer outputs, concordance for the classifications was only ~70%, and this was no better for the older infants (>12 mo) than for the younger infants (<12 mo). With a sample of 20-mo-old toddlers, Van Cauwenbergh et al (47) recently reported accelerometer activity counts to be significantly and positively associated with mean OSRAC-P activity intensity levels as scored during free play. The authors cautioned, however, that despite their utility for quantifying activity in toddlers, the accuracy of classifying play into sedentary behavior, light PA, or moderate-to-vigorous PA with the use of accelerometers was relatively poor. Nevertheless, accelerometers have shown reliable consistency in measuring activity levels when assessed in 24-mo-olds across settings such as at home or in the laboratory (48).

**THE IMPORTANCE OF PA**

Scores of studies document the role that undernutrition, namely inadequate protein-calorie nutrition, plays in compromising early development. With respect to PA, a persuasive line of research has shown that overall undernutrition in infancy will reduce motor activity. Lessened PA by the infant likely triggers a “functional isolation” (49) that flattens affect and limits the amount of attention given and received, resulting in less learning and lower mental development as well (50). Apart from general undernutrition, separate work has documented the impact of zinc deficiency (51) and iron deficiency anemia (52) on reducing motor activity in human infants. Indeed, by using accelerometers the Lozoff group showed total motor activity to be lower in anemic compared with nonanemic infants at 6 mo, with the magnitude of the differences increasing at 12 and 18 mo (53).

Aside from its impact on mental abilities, lower PA has also been linked to infant weight status in some reports. For example, a study in formula-fed infants found that percentage of body fat was inversely related to infant activity level as scored by observers (with a tool also normed on preschoolers), and the correlations became stronger with increasing age over the first year (54), suggesting that fatter infants are less active later in infancy. However, in a study in breastfed infants (55), no consistent associations were found between energy intake, weight, and maternal observations of activity level over the first year. Unfortunately, more recent work does not make the pattern much clearer. Slining et al (14) reported that activity level on the IBQ was not a significant predictor of infant weight-for-length z scores (WLZs) when measured concurrently at 3, 6, 9, 12, or 18 mo. Yet, their analyses showed that higher activity levels were associated with lower subsequent WLZs for all time points, suggesting that more-active infants are leaner later in infancy. An exception was activity level at 9 mo, which predicted higher WLZ at 12 mo.

In an early study, Rose and Mayer (56) showed that actometer-measured activity in 4- to 6-mo-old infants read 3 times over 48 h better predicted body size at 5 mo than did caloric intake. Mack and Kleinhenz (57) also used actometers with a small sample of infants at high risk of obesity given their obese mothers and low-income status. They found that over the first 2 mo of life, the 2 least active of the 5 infants stayed the least active, consumed the most calories, and gained weight faster than the other 3 infants. From a different perspective, in a contemporary investigation the possibility that excess activity might impair growth was explored (58). Eight preterm infants (gestational age of 36.4 wk) were monitored with accelerometers over 5 d. As would be expected, there was a moderate positive correlation between caloric intake and weight gain. But, of relevance, a stronger negative correlation was shown between activity and weight gain.

**A NOTE ON SEDENTARY BEHAVIOR**

Although sedentary behavior represents the conceptual opposite of high PA, its abundance has been linked to obesity in adults (59) as well as children (60). Relatively little research has addressed sedentary behavior in infants specifically (47), but one research group reported ~59% of indoor and 31% of outdoor behavior by 2-y-olds in child care centers to be classified as sedentary (39) by using the OSRAC-P observational coding system. More data are available on television and other uses of media with infants, where it is estimated that anywhere from 33% to 63% of infants from age 0 to 2 y watch television (61, 62). Indeed, Zimmerman et al (63) reported that, based on >1000 telephone surveys with caregivers, ~40% of 3-mo-old...
infants in their sample watched television, DVDs, or videos daily, and the proportion reached 90% by 24 mo. In light of the American Academy of Pediatrics’ (64) recommendation of no television at all for children under 2 y of age, it is disheartening to see that infants as young as 3 mo may be watching 40 min of television each day (63), with >10% of 1- to 2-y-olds watching for >2 h/d (65). If television watching displaces even 1 h of time that could be spent in active movement during wakeful periods, the impact on overall PA could be sizable.

CONCLUSIONS

Relative to work on nutrient intake and growth in infancy and toddlerhood, research on PA is limited. During the first postpartum year, normal activity levels differ from infant to infant. Although young infants show a limited repertoire of purposeful movements, by 12 mo of age the typical infant is walking unassisted, greatly increasing the opportunity for increased PA. Of the variety of techniques that allow for gauging PA in infancy and toddlerhood, caregiver questionnaires, direct observations, and motion sensors have been used most frequently. Although each method has shown its utility, the limitations of each must also be acknowledged.

Questionnaire ratings of activity allow for comparisons across infants or even comparisons within subjects over time, but they do not provide a quantifiable indicator as to the amount of PA. Moreover, the subjectivity inherent in a caregiver’s judgment of her own infant is also an obvious concern, irrespective of the moderate degree of stability shown for maternal ratings on the IBQ over the first year (66). For research use, observations require a good deal of prior training to ensure adequate interobserver agreement, and a number of the studies that have used infant samples have used systems that were normed on children ≥3 y of age. Finally, accelerometers, although easily the most objective in their ability to quantify levels of PA, would be prohibitively expensive for a large-scale, cross-sectional study. Of the most objective in their ability to quantify levels of PA, would be prohibitively expensive for a large-scale, cross-sectional study. Accelerometers, although easily

The sole author had full responsibility for writing the manuscript. The author did not have any conflicts of interest.

REFERENCES

PHYSICAL ACTIVITY IN INFANCY 733S

46. Tulve NS, Jones PA, McCurdy T, Crogan CW. A pilot study using an accelerometer to evaluate a caregiver’s interpretation of an infant or toddler’s activity level as recorded in a time activity diary. Res Q Exerc Sport 2007;78:375–83.

PHYSICAL ACTIVITY IN INFANCY 733S