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The impact of object carriage on independent locomotion

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ABSTRACT

The current study examined whether carrying objects in one's hands influenced different parameters associated with independent locomotion. Specifically, 14- and 24-month-olds walked in a straight path under four conditions of object carriage – no object (control), one object carried in one hand (one object-one hand), two objects carried in each of the hands (two objects-two hands), and one object carried in both hands simultaneously (one object-two hands). Although carrying objects failed to influence a variety of kinematic parameters of gait, it did affect children's arm postures, with children adopting less mature arm positions when carrying objects. Finally, arm position was related to walking skill, but only for older children when they were not carrying objects. These findings indicate that although a relation does exist between arm positions and gait parameters, this relation is easily disrupted by carrying loads, even small ones.

Learning to move efficiently around one's world certainly has significant survival value, but it also presents numerous challenges for young learners. As an example, the advent of independent, upright walking increases one's locomotor efficiency in that it allows children to go from one location to another while leaving their hands free to do whatever they wish. This efficiency of movement comes with a cost, however, in that it poses a wealth of challenges for young walkers, including maintaining one's balance at each step, given that one's centre of mass continually moves outside of one's base of support (Garciaguirre, Adolph, & Shrout, 2007). Maintaining balance is especially difficult due to children's disproportionate body dimensions (i.e., being top-heavy, Palmer, 1994) and inexperience with the dynamic disequilibrium (Bril & Brenière, 1992) brought about by standing on two feet. Regardless, by the end of the first year, children accomplish this feat. What makes this development possible?

According to Bril and Brenière (1992), learning to walk is a two-stage process wherein the crucial improvement is in balance control. The first stage, which occurs within four to five months of independent walking, involves integrating all the different gait elements (e.g., step width, walking velocity), allowing them to work together to support the body during forward propulsion. This achievement is followed by the second stage, which involves a fine tuning of these parameters with respect to changing environmental demands. In other words, children learn to put all the important elements into play, and once they get the hang of it, they then adjust to varying situations. Accordingly, practice is vital in this process.

The role of walking experience in locomotor development is reflective of a child's opportunities for learning (Schmuckler, 1996) and has been examined under a variety of situations, including crossing barriers (Kingsnorth & Schmuckler, 2000; Schmuckler, 1996, 2013b), climbing stairs and slopes (Adolph, 1995; Adolph, Eppler, & Gibson, 1993), gap crossing (Zwart, Ledebt, Fong, de Vries, & Savelsbergh, 2005), and carrying loads (Garciaguirre et al., 2007; Vereijken, Pederson, & Størksen, 2009). For instance, Kingsnorth and Schmuckler (2000) examined the factors that influenced children's abilities to cross over barriers and found that for 14- to 30-month olds, from a range of anthropomorphic, skill, and experiential variables, walking experience best predicted children's performance. Similarly, Zwart et al. (2005) found that the best predictor of gap

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crossing in toddlers was walking experience, and Vereijken et al. (2009) found that children's abilities to compensate for different loads placed on their bodies were related to walking experience. These studies underscore the value of experience, and suggest that with more opportunities, children learn to better deal with the challenges that accompany locomotion.

One obvious indication of such learning is observable in improvements in children's walking skill, with previous work demonstrating that walking experience is correlated with walking skill (Adolph, 1995; Bril & Brenière, 1992; Burnett & Johnson, 1971). Walking skill involves an inter-play of several variables, and can be reliably quantified into a number of different components that are generally related to one another (Adolph, 1995), such as stride length, step width, dynamic base, and so on (Adolph, 1995; Bril & Brenière, 1992; Kingsnorth & Schmuckler, 2000; Ledebt, 2000). Overall, such studies have demonstrated that walking skill, as assessed by parameters such as these, significantly predicts performance across a range of locomotor tasks, including the ability to traverse up and down slopes (Adolph, 1995).

Locomotor abilities do not develop independently of the growth of other motor components, however. Ledebt (2000), for example, has demonstrated a relation between such kinematic parameters of walking skill and motor control in one's upper torso. Specifically, Ledebt observed that changes in the breadth of base were closely related to changes in arm posture, such that as step width became more adult like (i.e., narrower distance between two feet), arm positions also became more mature (i.e., gradually lowered, with arms swinging in opposite phase). Ledebt (2000) argued that although the hands are no longer required for actual forward movement (as opposed to, say, crawling), the arms still play a role (via their position) in controlling posture and balance when walking. Along these lines, arm position (or "arm guard" as it is called) is characterized by a combination of specific rotations in the shoulders, the degree to which the elbows are bent, and the position of the entire arm. Reciprocal arm swing marks the most mature form of arm position, and is important for walking in that it minimizes the vertical displacement of the centre of mass by counterbalancing trunk rotation as a person steps forward. Thus, reciprocal arm swing increases postural stability and stepping efficiency (Elftman, 1939; Murray, Kory, & Bernard, 1967) and mimics adults' arm position when walking. However, when learning to walk, infants do not initially adopt reciprocal arm swing. Instead, Burnett and Johnson (1971) found that when first walking, children employ a high guard arm posture, described as externally rotated at the shoulder and flexed at the elbow, to help maintain their balance. This high guard position represents, then, the least mature (or adult-like) arm position. Children adopt this position for only a short period of time (Kubo & Ulrich, 2006; Ledebt, 2000), however, and quickly learn to adjust their arm positions throughout childhood, achieving reciprocal arm swing by 18 months, and using it systematically by 42 months (Ledebt & Bril, 2000; Sutherland, Olshen, Cooper, & Woo, 1980). Interestingly, Burnett and Johnson (1971) also observed that children will return to less mature arm positions to cope with situations that impede their balance; thus, situations that impede postural control affect arm guard position.

One common real-world situation that might potentially influence posture occurs when children carry objects with their hands. Carrying objects can impose changes on children's posture because it could not only potentially change children's centre of mass (Garciaguirre et al., 2007), but it also competes with the use of the arms for balance. Object carriage is actually quite a natural task for children. Karasik, Adolph, Tamis-LeMonda, and Zuckerman (2011) examined spontaneous carrying of objects in the home, and found that children frequently carried objects from one location to another, and they did so even before the advent of independent walking. For instance, crawling infants would put objects in their mouths or carry objects under their arms. However, walking infants largely transported objects using their hands, with the most preferred objects they carried being small toys. These authors also found that walking experience facilitated object transport, with more experienced children being better able to adjust their posture when carrying. Interestingly, Karasik et al. (2011) also found that less experienced walkers actually benefited (i.e., fell less) when carrying objects, suggesting that hand occupancy helped early walkers to be more vigilant in controlling their balance.

Carrying objects is also of interest in that it creates a naturalistic situation of load carrying for children. Previous work on load carrying has focused mainly on how children adapt when external loads (i.e., weights) are literally strapped onto their bodies. This work has revealed that loads impact young infants' walking, causing changes in gait parameters and walking disruptions such as falls and missteps (Garciaguirre et al., 2007; Kistner, Fiebert, & Roach, 2012; Vereijken et al., 2009). With experience, however, children are able to make the necessary postural adjustments (e.g., leaning against the load, Garciaguirre et al., 2007) and footfall modifications (e.g., walking slower, making smaller steps, Adolph & Avolio, 2000; Garciaguirre et al., 2007; Vereijken et al., 2009) when carrying loads.

Furthermore, such interlimb changes may be due to ongoing changes in the central nervous system (Gesell, 1939). This idea was supported by Corbetta and Bojczyk (2002) who examined whether changes in reaching patterns co-occurred with the onset of independent walking. Specifically, the researchers assessed whether infants reverted to two-handed reaching at the onset of walking and resumed adaptive uni-modal reaching when they were better able to control balance while walking. Examining infants longitudinally in posture and locomotion tasks, as well as in reaching tasks, the researchers found that infants' two-handed reaching increased at the onset of walking, but adaptive reaching occurred after infants became more stable in upright locomotion. Because children were learning upright balance which required greater upper arm coupling, children also opted for arm coupling in reaching for objects. The researchers argued that such changes reflect ongoing neuromotor reorganizations.

In the present study, instead of having external loads strapped onto children's bodies, the children were asked to carry objects that varied the load distribution on their hands, and thus, systematically changed the dynamics of the hand posture and movements. Given the work on load carriage, it is reasonable to wonder what impact carrying objects will have on different components of children's locomotion. Specifically, the present study examined how object carrying would impact: (a) walking skill (i.e., gait parameters), (b) arm guard position, and (c) the relation between walking skill and arm guard