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To have and to hold: embodied ownership is established in early childhood

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Abstract

We investigated whether embodied ownership is evident in early childhood. To do so, we gifted a drinking bottle to children (aged 24 to 48 months) to use for two weeks. They returned to perform reach-grasp-lift-replace actions with their own or the experimenter's bottle while we recorded their movements using motion capture. There were differences in motor interactions with self- vs experimenter-owned bottles, such that children positioned self-owned bottles significantly closer to themselves compared with the experimenter's bottle. Age did not modulate the positioning of the self-owned bottle relative to the experimenter-owned bottle. In contrast, the pattern was not evident in children who selected one of the two bottles to keep only after the task was completed, and thus did not 'own' it during the task (experiment 2). These results extend similar findings in adults, confirming the importance of ownership in determining self-other differences and provide novel evidence that object ownership influences sensorimotor processes from as early as two years of age.

Property is significant in most societies: who has access to it – or not – is the basis of formal and informal rules and regulations. Moreover, self-owned items are judged more positively and are attributed a higher value compared with other-owned items (Beggan, 1992; Kahneman & Tversky 1984; Kahneman, Knetsch & Thaler, 1991) and become part of the Extended Self (Belk, 1988). There is evidence that fundamental representations of ownership emerge in early childhood (e.g., Ross, Friedman & Field, 2015).

Ownership during development

Children articulate and codify ownership rules in both verbal and non-verbal communication as early as 12 months of age. For example, infants correctly retrieved one of two balls that an experimenter labelled as “my ball” (Saylor, Ganea & Vazquez, 2011). Ownership terms first manifest around age 18 months, when toddlers begin to use personal pronouns referring to themselves (e.g., I, me, mine). They vary in frequency into the second and third years of life, when use of second person pronouns also appears (Hay, 2006; Lewis & Ramsay, 2004). Hay (2006) found that toddlers’ use of first (e.g. “mine”) and second person (e.g. “yours”) possessive pronouns were correlated in 18 to 30 month olds, suggesting an emerging understanding of the concept of ownership, as opposed to a simple tendency to repeat the word “mine” when competing with peers for toys. From 24 months onward, children can identify and label objects that belong to themselves, their mother, or another individual (Fasig, 2000; Brownell, Iesue, Nichols & Svetlova, 2013).

Object ownership recognition is also evident in nonverbal behaviour of toddlers: Ross et al (2015) gave 24- and 30-month old children toys and then had them free play in dyads with both of their toys, and a third unowned toy. Children spent more time in physical contact with their own toys compared with the other child's, or the unowned toy. Furthermore, as young as age two years, children show an endowment effect, preferring toys designated as theirs over toys that are similar or identical in appearance but labelled as someone else's (Gelman, Manczak & Noles, 2012). From age three years, ownership is so salient that children can track accurately their own toy that has been scrambled among others, even if the distractors are physically identical (Gelman et al, 2012). It is also clear that for children as young as three years, the toys they own are an extension of the self. They often react with anger when a toy is removed from them (Piaget 1932; see also Belk, 2014; Furby, 1978; McClelland, 1951). After feedback on tasks which decrease their self-worth, five year old children are less willing to part with their valuable toys (Diesendruck & Perez, 2015). This indicates that object ownership can modulate self-esteem and thus contribute to the Extended Self in children (Diesendruck & Perez, 2015) as well as adults (Belk, 1998). Similarly, evaluation of own toys is greater in three- to four-year-old children who make pictures of themselves thus increasing their self-focus, compared with making pictures of other people (Hood, Weltzien, Marsh & Kanngiesser, 2016).

Object ownership also influences toddlers' interactions with others. For instance, five- but not three-year-olds generate and comprehend nonverbal signals indicating property ownership (Rossano, Fiedler & Tomasello, 2015), but two- and three-year-olds nevertheless protest when someone claims or attempts to dispose of clothing that belongs to them (Rossano, Rakoczy, & Tomasello, 2011). Similarly, Eisenberg-berg, Haake, Hand and Edward (1979) observed that children between 2.5 and 5 years of age blocked or protested against peers' attempts to play with toys that had been designated as theirs, but showed significantly fewer defensive behaviours toward toys belonging to the whole classroom.

Thus children conceptualise ownership in the verbal and behavioural domains from two years, and it is established by three years of age. Moreover, ownership influences their interactions with objects and with other people. Here, we investigate whether the concept of ownership is 'embodied' in young children's simple sensorimotor actions with objects. We start with considering the embodiment of cognitions and affect, as context for embodied ownership.

Embodiment of affect and cognitions

The theory of embodied cognition proposes that cognitive states and sensorimotor experiences subtly and unconsciously shape each other during real-time processing (Loeffler, Raab & Cañal-Bruland, 2016; Prinz, 1997). Thus, when considering the future, adults tend to lean forward slightly; when thinking about the past, they tend to lean back (Miles, Nind, & Macrae, 2010). Motor behaviour in turn influences cognitive processing: assuming facial musculature associated with particular emotions alters the comprehension of a model's congruent or incongruent facial expressions (Niedenthal, 2007). In developmental psychology, there has been a strong focus on how sensorimotor experience influences cognitive process and development (see Needham & Libertus, 2010 for a review) but as yet there is no demonstration that abstract concepts such as ownership can impact sensorimotor processing in children. Behaviours such as protoimperative pointing and self-reference effects do indicate some forms of embodiment from 10 months of age, where actions are combined with verbal spatial reference labels (Capirci, Contaldo, Caselli, &

Volterra, 2005), and become meaningful gestures referring to specific locations in relation to the self in space (Pizuto & Capobianco, 2005).

In adults, cognitive and sensorimotor links can be investigated with kinematic parameters. For example, Glover, Rosenbaum, Graham & Dixon (2004), measuring grasp parameters for reaches to small and large fruit, showed that when the word for a small fruit (“cherry’’) was superimposed on a large fruit (apple), the grasp parameters adjusted such that they were more consistent with a smaller object, as the conveyed by the meaning of the word.

Similar dissociations have been reported for semantically cued movements in the vertical plane (Kritikos, Dozo, Painter & Bayliss, 2011). Participants were cued to reach for and grip the top or the bottom of a vertically oriented dowel by the location of a word at the top or the bottom of a computer monitor. Concurrent with the reaching movement, they read aloud the word, whose meaning was location congruent or incongruent (e.g. top -‘high’ or top - ‘low’). Articulating the location-incongruent word altered the final vertical position of the grip, such that it was lower when participants reached for the top while saying a top-incongruent word, compared with saying a top-congruent word (Kritikos et al, 2011).

Embodied ownership

In our previous demonstration of embodied ownership in young adults (Constable, Kritikos and Bayliss 2011; Constable, Kritikos, Lipp & Bayliss, 2014), we gifted a white mug to undergraduate participants, asked them to decorate it with their own design, and had them use it for 10-14 days. Then, participants returned to the lab where they performed a simple reach-grasp-lift-replace task with their own, the experimenter’s or a blank (unpainted and unowned) mug. Acceleration and deceleration for the lift and replace actions were higher for the self- than for the experimenter-owned mug. This was attributed to a social imperative to be careful with another's belongings. In another condition, the actual owner of the experimenter mug was a confederate who was not present during testing, but who gave her mug to the Experimenter to be used for the duration of the session. Here, acceleration and deceleration of the lift for self- and other-owned mugs were not clearly dissociated (Constable et al., 2014). This pattern possibly reflects social etiquette and social norms: being seen to take care with another's belongings in their presence, but being less careful in their absence. Importantly, however, in all these experimental manipulations, at the peak of the lift movement young adult participants consistently positioned their own mug closer to themselves, and the experimenters' mug away from themselves (Constable et al 2011; 2014). Thus, the nature of the interaction with property differs depending on ownership (Constable et al 2011; 2014), and kinematic recordings can be informative about the links between cognitive and sensorimotor processing.

While many amplitude and temporal kinematic parameters can be generated, we were interested in investigating spatial parameters (location in space) that reflect the positioning of items in relation to the self. Specifically, we generated parameters that could reflect sensorimotor experience and real-time processing (Loeffler et al, 2016; Prinz, 1997), in this case of the item and the current and predicted sensory state of the hand and arm in the course of the movement trajectory.

As outlined above, the influence of sensorimotor experience commences in early childhood. There are indications that this takes into account spatial locations in relation to the self, for example, tracking own toys (Gelman et al, 2012), increased physical contact with owned toys (Ross et al, 2015), as well as gesturing far and near in protoimperative pointing tasks (Capirci et al, 2005). Hence, an object that may be considered to be an extension of the self should be positioned closer to the self. Indeed, Prelinger (1959; cited in Belk 1988) considered proximity to be important in promoting extension of the self, with objects closest to us, such as our body parts, are linked to the self more strongly than distant objects such as items of furniture in the room. Thus, if owned property is embodied, and is incorporated into the self, self-owned items (bottles) should be positioned closer to the body during the movement (represented by the y maximum value) as well as the final point of the lift phase movement (represented by the y at peak lift value).

In the current study, we followed the paradigm of Constable et al. (2011; 2014) as closely as possible in applying it to young children, to assess whether embodied ownership manifests in early childhood in terms of motor behaviour. We analysed the actions of 47 preschool children. We gifted them with a drinking bottle and had them use it for about two weeks, to ensure that they were familiar with its physical properties and for consistency with our previous protocol (see Constable et al, 2011; 2014). Then, children visited the lab where they completed a simple reach-lift-replace task with either their own or the Experimenter's bottle. We recorded the 3D displacement of the bottle through space in x-, y- and z-plane coordinates with motion capture equipment (Oqus, Qualysis). Based on the language and behavioural observation literature reviewed above, we assumed that kinematic parameter indicators of embodied ownership would emerge at two years of age, therefore we tested children from 24 months to 48 months (two- to four-years-old). Verbal and / or motor delays in development may affect comprehension of instructions and variability in motor output, as might undiagnosed autism. Thus we administered a set of screening tests and questionnaires to exclude this as a factor in any variations in children's performance. We expected that there should be reliable differences in positioning self- versus experimenter-owned bottles during the movement. Specifically, after picking it up, children should show a bias for positioning the self-owned bottle closer to themselves than the experimenter-owned bottle, consistent with our previous work. Using motion capture recordings and analysis, we calculated the position of the bottle in the y (sagittal) plane at peak height of the lift (see also Constable et al, 2011; 2014). We also calculated, from the initial starting position on the table, the maximum distance in the y plane and away from the child's body that the bottle occupied during the movement trajectory (y maximum).

Method

We tested each child individually in two sessions, a) screening (autism screening, fine motor and language development measures), and b) testing (motion capture recording of a reach-grasp-lift-replace task). Participants performed natural lifting actions with self-owned or experimenter-owned drink bottles. The protocol was approved by The University of Queensland Ethics Review Board Committee. Written informed consent was obtained from the children's parent or guardian prior to commencing the first, screening session.

Participants

Seventy-eight children aged 23 to 48 months were recruited and completed the screening session. One child met the criteria for autism but did not return for the second session and was not included in the analysis. Of the remainder, 58 returned for the motion capture session. We were able to use the data of 47 out of these 58 children to analyse two kinematic parameters of interest. The mean age of the 47 children was 33.81 months (SD 6.23, range 23 to 43 months). Not all 47 children contributed equally to these two parameters, however. For some children (12 of the 47) we could not generate reliable end-of-movement recordings for y at peak lift, and N for the y at peak lift parameter was 35. Conversely, recordings for y maximum, the second parameter, were reliable for all 47 children (see below, and Table 1 of the Supplementary data for inclusion and exclusion details).

Exclusion criteria were established prior to commencement of the study. We excluded trials and/or participants from analysis due to insufficient and/or ambiguous trials, parental influence, technical issues, poor task engagement, bottle lost or forgotten, or excessive fussiness (see Table 1 in Supplementary data for details). We defined excessive fussiness as refusal to sit in the chair, and/or refusal to attend to or engage with the bottle lifting game, and/or comply with task instructions, and/or inconsolable irritation, discomfort, or crying in the experimental setting. Using motion capture analysis software, we excluded unreliable trials, defined as reach trajectories that could not be processed due to: insufficient recording by the motion capture cameras (e.g., any movements outside of calibrated camera space; reflective markers lost or obstructed); erratic movements (e.g., banging, throwing) or movements not complying with instructions (e.g., bottle turned upside down during lift). Occasionally, the child did not comply with the instruction to lift the bottle, but rather pushed it towards the experimenter or pulled it towards themselves along the tabletop or close to its surface. Movements were considered push/pull when the motion capture software showed the bottle marker z coordinates did not change, and subsequent video recording viewing of the trial showed that the movement remained under the level of the child’s shoulders, and/or the bottle remained in contact with the table during the majority of the movement trial. These trials were excluded from the ‘y at peak lift’ analysis (see definition below) because a clear lifting movement programme was not activated.

Therefore, push-pull trial biomechanics and kinematics are not comparable with those of lifting trials. All the above exclusion details were verified subsequent to the analysis through concurrently collected video recordings (See Supplementary tables 1 and 2).

Four children sat on their parents' lap during testing, for an average of 5 trials (range four to 6 trials). Three children had their parent sit beside them for four, two and two trials respectively. None of the older children sat on the parent's lap or had the parent beside them during testing. Of the 58 children undertaking the lifting task, 30 required a verbal prompt. Twenty-three of the 47 children included in the analysis required a verbal prompt ("Lift it up") on at least one of the trials during the bottle lifting task (see Table 1 in Supplementary data).

Based on the above criteria, we aimed to collect a minimum of four valid self-owned bottle lifting trials and four valid experimenter-owned bottle lift trials from each child (a minimum of eight valid trials in total). Where fewer than four/four useable trials were collected, the participant was excluded from analysis. If the child appeared engaged and willing, and performing the task appropriately, testing continued to obtain up to a maximum of 42 trials (see Table 1 in Supplementary data for details). Trials were coded by the experimenter (JL), who was not blind to the condition. It is possible the number of excluded participants (31 of 78) is inflated because children needed to attend twice, increasing chances of non-attendance of the second session. We also set an inclusion criterion of four valid trials minimum per condition (total 8 valid), which was difficult for some children to achieve.

Apparatus and Stimuli

Screening session. To screen for possible early signs of autism spectrum conditions, or developmental delay in children aged up to 30 months, we administered the Modified Checklist for Autism in Toddlers (MCHAT; Robins, Fein, & Barton, 1999; 23-item yes/no format parent questionnaire). To screen children older than 30 months, we used the Social Communication Questionnaire (SCQ; Rutter, Bailey, Lord, 2003; 40-item yes/no format parent questionnaire). To assess fine motor development for children aged 23-42 months, we administered the fine motor subscale of the Bayley Scales of Infant and Toddler Development: Third Edition (Bayley-III; Bayley, 2006). For fine motor development for children older than 42 months, we used two subtests of the Peabody Developmental Motor Scales and Activity Scales (PDMS-FM-2; Folio & Fewell, 2000); Grasping and Visual-Motor Integration. We gauged children's developing abilities in early domains of language (including vocabulary, and production) by giving parents of children aged up to 30 months the MacArthur Communicative Development Inventory's Words and Sentences (Lewis & Ramsay, 2004) to administer at home. For children older than 30 months of age, we administered the Peabody Picture Vocabulary Test, Fourth Version (Dunn & Dunn, 2007) during the screening session to assess receptive vocabulary. No children met the criteria for motor, or verbal delay; one child met the criteria for autism and was excluded from the analysis.

At the conclusion of the screening session, children were gifted a drinking bottle. Depending on the age of the child, these were either plastic Nuby 295ml Sports Sipper (height 20cm, width at grasping location 4.5cm, width at top and bottom 6cm) or aluminium bottles[1] height 25cm, width at grasping location 7cm, width at top and bottom 7cm). Parents were given a take-home record sheet to record use of the drink bottle, and a take-home questionnaire to collect information about siblings, attendance at childcare or school, and general comments about their child's ownership behaviour.

Motion Capture Session. For each participant, their bottle (self-owned), and a size-and-shape identical bottle in a different colour introduced as the experimenter's bottle (experimenter-owned), were the objects of the reach-grasp-lift-replace actions. Children performed lifting actions with each bottle, while an Oqus (Qualisys) six infra-red light-detecting camera system (recording at 100Hz, calibrated to < .6mm accuracy) tracked the displacement of half-sphere lightweight markers (4mm) placed on the drinking bottles. One marker was placed on each bottle 1.5 centimetres below the base of the bottle screw-top lid. An additional reflective marker was placed on each experimenter-owned drink bottle, two centimetres from the base of the bottle in vertical alignment with the first marker, which served as a reference to distinguish the drink bottles during motion capture data processing. Kinematic data were collected on a Dell Optiplex 9020 desk computer and processed and analysed off-line using Qualisys software.

During the testing session, bottles were hidden inside black cloth-covered boxes (height 21.5cm, width 26cm, depth 14.5cm for Nuby bottle, height 26cm, width 24.5cm, depth 18cm for aluminium bottles) before they were revealed to the children. Children were seated at the testing table (height 120cm, width 90.5cm, depth 45cm), and encouraged to begin each trial by placing each hand on the starting positions indicated by two felt animal stickers (8cm from table edge). To maintain interest in the testing session, and to minimise

[1] One child in the youngest age group (24-30 months) had an aluminium bottle.

boredom, trials were interspersed with completing simple jigsaw puzzles of everyday items (e.g., food, toys, animals).

Design and Procedure

Children were tested individually in two sessions. In the initial screening session (approximately 30 minutes), parents/guardians gave written informed consent for their child to participate in the study. Children spent a few minutes in the warm-up room becoming acquainted with the experimenter while playing with toys. When settled, they were directed to the testing room and administered the age appropriate screening items as detailed above. At the end of the session, children and parents were thanked, and presented with a gift for participating (the drink bottle). Children younger than 36 months were presented with a plastic Nuby bottle, while children older than 36 months were presented with an aluminium bottle. The parents were asked to have their child use the bottle as much as possible (home, daycare, school). They were also asked to keep a record of their child's estimated bottle usage on a record sheet provided. The child and experimenter both had either an aluminium or Nuby bottle, which differed in terms of colour but otherwise had the identical physical dimensions and lid-and-spout shape. The colours of the bottles were counterbalanced across children, as was the colour of the bottle assigned as the experimenter's bottle.

The motion capture session (approximately 30 minutes) was conducted approximately 14 days later, reflecting the paradigm of Constable et al (2011; 2014). Upon arrival, children were seated at the table, while the parents sat behind them in the same room. If children were restless or fussy, parents could sit beside the child, or children could sit on their parent's lap. As a warm up task, children were introduced to a puppet that needed help with a puzzle, and were instructed to help him complete it. While children were completing the puzzle, the experimenter ensured the bottle was empty of liquid and surreptitiously attached the reflective markers to the bottles. The children were told that they would be playing a bottle game, and were introduced to two drink bottles. The experimenter introduced the child's drink bottle by saying, "This is your bottle, [child's name] bottle" and placing that bottle on the table in front of the child. The experimenter then introduced the experimenter's bottle by saying, "This is my bottle, [experimenter's name] bottle" and placing the bottle on the table in front of themselves. The experimenter then repeated these introductions.

Children were instructed that they would be playing a lifting game with the bottles. To ensure they understood the task, in the practice trials, using her own bottle, the experimenter demonstrated how to lift the bottle (grasping bottle with one hand, lifted the experimenter's bottle vertically above the start position on the table, at a height above their head) and returned it to the table. The experimenter asked the child to lift her / his own bottle the same way, and gave the child time to demonstrate the action. Constable et al (2011; 2014) had participants close their eyes while the items were set before them, and then were instructed to open their eyes and perform the reach-grasp-lift-replace action. To ensure similar control over viewing the bottles prior to the action, here we concealed the placement of the bottle under a box, rather than relying on the children to open and close their eyes on command. After the practice lifts, the child was introduced to the box in which bottles were hidden during the lifting game. The experimenter explained that bottles would be hidden inside the box, that the experimenter's job was to lift up the box, and the child's job was to lift the bottle inside the box. Children were told that when the box lifted, they should pick up and lift the bottle and then return it back down to the table. The experimenter placed the black box on the table with the hollow aspect of the box facing her, and then placed one of the bottles inside the box such that it was positioned 10cm from the starting hand positions. A felt animal sticker on the table served as a reference for the experimenter to place the box and drink bottle consistently on the same starting position. Note that because this bottle starting point was visible, we felt that calculating the final replacement position of the bottle would not yield a valid measure of embodiment. Children were encouraged to place their hands on the felt animal stickers on the table, which served as the starting points. The experimenter asked if child was ready, and said “Lift it up”, while simultaneously lifting the box to reveal the bottle. If children did not understand the instruction, or began to make unusual movements throughout the testing session, the verbal prompt was adapted to be “Up and down”. If the child did not lift the bottle, the experimenter would repeat the instruction with a gestural prompt (made a lifting action with their hand).

Motion capture recordings for the experimental trials began when the child understood the task and complied with instructions. Approximately two practice trials were conducted and recorded. The experimenter manually triggered motion capture cameras to begin recording immediately prior to the box being lifted. The motion capture cameras were programmed to stop recording automatically after 6000ms – 10000ms depending on child’s age and/or ability. Depending on age and perceived interest level of the child, blocks of either four or eight trials per block were conducted, with trial order counterbalanced across blocks (Own-Exp-Exp-Own, Exp-Own-Own-Exp etc.). Between blocks, the experimenter re-introduced the monkey puppet and a simple puzzle, and the child was invited to complete several pieces before the bottle-lifting task continued. At the completion of testing, children and parents were thanked and presented with a certificate and gift of appreciation (e.g., toothbrush and toothpaste, crayons, chalk, activity book).

Calculation and analysis of spatial positioning measures: mean y at peak lift and mean y maximum

Movement in Cartesian coordinate space (x = horizontal; y = sagittal; z = vertical) was captured by the Oqus Qualisys camera system. For each trial, we determined the coordinate of the bottle in the y (sagittal) plane when the bottle was at the maximum in the z (vertical) plane, that is, at the peak of the lifting phase, ‘y at peak lift’, and derived the mean value for all useable trials. For each trial, we also calculated ‘y maximum’: this was the maximum displacement (away or towards the child’s body) in the y plane from a hypothetical vertical line, originating from the staring position of the bottle’s marker, that the bottle achieved during the trajectory (Constable et al, 2011; 2014). We derived the mean value for all useable trials. The measurement units were millimetres, for both y at peak lift and y maximum. Negative values denote distance from 0 towards the self; positive value denote distance from 0 away from the self (towards the experimenter).

To facilitate subsequent analyses, for both mean values for y at peak lift and mean values for y maximum, we derived a single self-other difference value as an index of positioning bias and conducted one-sample t-tests. This is comparable to paired-sample t-tests, and has the advantage of controlling for variability of movements between participants. Specifically, for each child we subtracted the mean value (in mm) for the Experimenter-owned bottle from the mean value score for the self-owned bottle:

$$\text{Y value}_{\text{Self}} - \text{y value}_{\text{Experimenter}} = \text{y difference value}$$

Moreover, based on this difference value, we could categorise each child as ‘self bottle closer’ or ‘self bottle further’ depending on whether this bias score was negative or positive.

Results

For the y at peak lift measure, the data of 35 children were included in the analysis. There was a comparable mean number of trials included in the self and experimenter comparisons (see Supplementary data for details of individual children, and comparisons of collected and included trials). Thus it is unlikely that there was a systematic rejection or inclusion of self or experimenter trials in the analyses.

To check indirectly for possible effects of boredom and disengagement in relation to age, we calculated rank-order correlations (Spearman’s ρ) between age in months and the total number of trials collected for each child, assuming that fewer trials might indicate lack of engagement with the task. For y at peak lift the correlation was non-significant, $\rho = .133$, $p = 0.447$, N = 35. For y maximum, the correlations was also non-significant $\rho = .192$, $p = 0.197$, N = 47, indicating that younger children did not become bored, as far as indicated by the number of trials they produced.

y at peak lift

Note that N is lower for this measure than y maximum (below), because we excluded participants whose final lift position was consistently out of the cameras’ recording range (see Table 1 in Supplementary data for details). For all analyses, significance was set at alpha < .05, two tailed. A one-sample t-test on the self-experimenter positioning bias score for y at peak lift (2-tailed, bootstrapped at 5000 samples) indicated that the mean value was significantly different from 0, $t(34) = 3.809$, $p = 0.004$, mean difference = -46.622, standard error = 11.971, 95% confidence interval = -70.899 to -23.873, Cohen's *d* = 0.644. This significant negative bias score indicates that, at the peak of the lift movement, children consistently positioned their own bottle closer to themselves than the experimenter's bottle. Figure 1 shows the mean self minus experimenter value for each participant, and the overall mean and median values (-19.08mm and -46.82mm respectively), indicating an overall bias for positioning the bottles closer to the self versus the experimenter (and see extra analyses in Supplementary data).

FIGURE 1 HERE

Correlations with age, use, number of valid trials and motor tasks

We calculated a rank-order correlation (Spearman's ρ) between age in months and self-other positioning bias for y at peak lift, which was nonsignificant ($\rho = -0.120$, $p = 0.506$, N = 35). Spearman's ρ correlations were also calculated between the y at peak lift self minus experimenter score and the scaled motor score of the Peabody Developmental Motor Scales and Activity Scales (PDMS-FM-2; Spearman's $\rho = -0.192$, $p = 0.319$, N = 29[2]), developmental age motor score (Spearman's $\rho = -0.189$, $p = 0.326$, N = 29[2]), parents' report of total use of the bottle (Spearman's $\rho = 0.120$, $p = 0.494$, N = 35) and the number of days owned (Spearman's $\rho = 0.119$, $p = 0.495$, N = 35). None of these variables correlated with y at peak lift. This indicates that spatial positioning of the bottle closer to the self in the y plane at peak lift was not associated with self-reports of usage or with motor development. We also conducted Spearman's ρ correlations with age in months, number of valid trials collected for each child and with the self minus experimenter score: number of valid trials collected

[2] Younger children are not included in this N because they were administered a different test battery, the Bayley Scales.

correlated significantly with age in months (Spearman's ρ = 0.578, $p < 0.0001$, N = 35), but not with the y at peak lift position (Spearman's ρ = -0.116, $p = 0.506$, N = 35). We believe this reinforces the overall pattern, indicating that ownership embodiment manifests by two years and there is little evidence of further increase with age.

y maximum

For all analyses, significance was set at alpha < .05, two tailed. Forty-seven children were included in this analysis. Preliminary analyses revealed that the assumptions of normality were violated. A one-sample t-test on the self minus experimenter score for y maximum (2-tailed, bootstrapped at 5000 samples) indicated that the mean value was significantly different from 0, $t(46) = 3.446$, $p = 0.001$, with a mean difference = -13.359, standard error = 2.542, 95% confidence interval = -21.162 to -5.556, Cohen's $d = 0.508$. Figure 2 shows the mean self minus experimenter value for each participant, and the overall mean and median values (-13.361 and -2.423 respectively), where negative values indicate a bias towards positioning the bottle closer to the self. Results indicate an overall bias for positioning the bottles closer to the self versus the experimenter. This significant negative bias score indicates that during the lifting movement's trajectory, there was an overall bias towards positioning the self-owned bottle closer to the body (and see extra analyses in Supplementary data).

FIGURE 2 HERE

Correlations with age, use, number of valid trials and motor tasks

We calculated a rank-order correlation (Spearman's ρ) between age in months and self-other positioning bias, which was nonsignificant (Spearman's ρ = -0.076, $p = 0.610$, N = 47). Spearman's ρ correlations were also calculated between the y maximum self minus experimenter score and age and the scaled motor score of the PDMS-FM-2; Spearman's ρ = -0.309, p = 0.034, N = 47), developmental age motor score (Spearman's ρ = -. 166, p = 0.266, N = 47), parents' report of total use of the bottle (Spearman's ρ = 0.020, p = 0.892, N = 47), and the number of days owned (Spearman's ρ = -0.003, p = 0.985, N = 47). Thus, only the scaled motor score correlated significantly with y maximum. This indicates that spatial positioning of the bottle closer to the self during the lift of the movement's trajectory was not associated with self-reports of usage, although there is some association with motor development. Because the correlation is with the scaled motor score, we speculate it reflects a greater reliability of movement. We also conducted Spearman's ρ correlations with age in months, number of valid trials collected for each child and with the self minus experimenter score. For y maximum, again the number of valid trials collected, correlated significantly with age in months (Spearman's ρ = 0.536, p < 0.0001, N = 47), but not with the y maximum position (Spearman's ρ = 0.130, p = 0.385, N = 47).

In summary, children positioned their own bottle closer to themselves compared with the experimenter's bottle, seen for both the y at peak lift and y maximum. For both parameters, self minus experimenter position values generally did not correlate with age or with verbal or motor performance.

These findings are consistent with our expectation that self- versus experimenter-owned positioning differences should be evident by two years, indicating established embodied ownership early in development. We do not think the effect was due to impulsive reaching and lifting when bottles were revealed, because then we would expect to see no bias on the positioning of the bottle closer versus further from the self. Children may have had a subtle, pre-existing colour preference for one of the two bottles, however, that was amplified by subsequent allocation and use of that bottle. Counterbalancing of bottle colours across children and across child-experimenter pairs probably minimised colour preference as the basis for the differences in self-other movement differences in Experiment 1, but we checked for this in Experiment 2 by allocating ownership after the lifting task.

Experiment 2

We analysed the data of a control group of 16 children in the 40-50 months age range on the bottle-lifting task and conducted an analysis on post-task selection of the bottle. Because in Experiment 1 age did not predict the systematic differences in the positioning of the bottles, thus we restricted the age of the sample to this upper age range for ease of participant recruitment. We conducted the same paradigm as above, but did not gift the child with a bottle at the end of the first session, nor did the Experimenter allocate a bottle to herself. Rather, at the conclusion of the task the experimenter asked the child to choose one of the bottles to take home as a gift.

We hypothesised that if the bias in self-other positioning is due to preference and thus selection of one colour / design over the other, then there may be some indication of systematic differences in positioning of the selected versus non-selected bottle. Importantly, these differences would be due to preference but not ownership, because the bottle will be allocated after the task is complete and children will not know that they will acquire one of the bottles.

Method

Participants

Nineteen children were recruited in total, but three were excluded, one child due to attrition, one due to experimenter error, and one due to unusual movements, leaving a total of 16 children in the analysis. The 16 children were aged 40-50 months at session 2, the motion capture session (*M* = 43.4 months, *SD* = 2.7, range 41 – 49).

Apparatus, Stimuli, Procedure and Kinematic parameters

These were identical to Experiment 1, using the same bottle pairings counterbalanced for colour, except for the crucial difference that the drinking bottle was not gifted at the end of the first screening session. Rather, children received a gift of appreciation (e.g., toothbrush and toothpaste, crayons, chalk, activity book) at the end of the first session. After two weeks, children returned for the second session and were introduced to a box, and were instructed that the experimenter did not know the contents of the box. After opening the box to reveal, sequentially, a stuffed toy (used for practice trials) and the drinking bottles, the experimenter stated "There are toys in this box. Nobody owns these toys. These toys don't belong to anyone. No one owns these toys, so it is ok for us to play with them today. We can play a lifting game with these toys". Practice trials were conducted with the stuffed animal toy, before beginning the bottle lifting task. The procedure was identical to that of Experiment 1. At the conclusion of the session, children were asked to select the bottle they would like to take home as a gift. Their choice was recorded, to compare against any spatial difference in the movement parameters (spatial positioning for selected versus non-selected bottle). The calculated kinematic parameter (y at z maximum for bottles during the lift phase of the action) was identical to that of Experiment 1.

Results

Consistent with Experiment 1, for both y at peak lift and y maximum we derived a single selected minus non-selected (corresponding to self minus experimenter) difference value as an index of positioning bias and conducted one-sample t-tests on this.

y at peak lift

For all analyses, significance was set at alpha < .05, two tailed. Preliminary analyses revealed that the assumptions of normality were violated, thus both parametric and non-parametric tests were conducted, and revealed a highly similar pattern of results. A one-sample t-test indicated that this was not significantly different from 0 (2-tailed, $t(15) = 0.350$, $p=.731$, mean difference = -4.0930, standard error = 11.69093, 95% confidence interval = -29.0116 to 20.8256, Cohen's $d = 0.00875$). This indicates that the positioning bias at the peak of the lift movement did not differ for the selected and non-selected bottles. Figure 3A shows the mean selected minus non-selected value for each participant, indicating no overall bias, and the overall mean and median values (-4.09mm and -2.12mm respectively).

y maximum

For all analyses, significance was set at alpha < .05, two tailed. Preliminary analyses revealed that the assumptions of normality were violated, thus both parametric and non-parametric tests were conducted, and revealed a highly similar pattern of results. A one-sample t-test indicated that the mean value was not significantly different from 0 (2-tailed, $t(15) = .720$, $p=.482$, mean difference -1.831, standard error = 2.542, 95% confidence interval = -7.249 to 3.587, Cohen's $d = 0.18$. This shows that during the lifting movement trajectory children positioned both the subsequently selected and non-selected bottles at a comparable distance from themselves. Figure 3B shows the mean selected minus non-selected value for each participant, indicating no overall bias, and the overall mean and median values (-1.832mm and 2.195mm respectively).

FIGURE 3 HERE

In summary, when ownership is not allocated to the bottles prior to the lifting task, both measures of positioning bias (y at peak lift and y maximum) indicate that there is no difference in positioning between the bottle that is ultimately selected and the one that is not selected.

GENERAL DISCUSSION

Based on previous studies suggesting that the conceptualisation of ownership emerges around age two (Fasig, 2000; Brownell et al, 2013; Ross et al, 2015) we expected indications of systematic biases in the spatial positioning of the self- versus other-owned bottles in our sample of 24 and 48 month-olds. We found that children positioned self-owned bottles significantly closer to themselves at the peak of the lift phase of the movement (y at peak lift). Moreover, during the lift phase of the movement trajectory, they positioned the self-owned bottle closer to themselves than the experimenter-owned bottle overall. This pattern indicates embodied ownership is evident as early as 24 months of age. Age (in months) did not correlate with this self-owned positional bias, nor with motor and verbal development scores. This pattern of spatial positioning of the bottles is consistent with that seen in young adults using the same object-lifting paradigm (Constable et al, 2011; 2014).

In Experiment 2, ownership was assigned after the lifting task. We analysed y at peak lift and y maximum in terms of the bottle selected versus not selected to take home at the end of the session. Children showed no bias in the positioning of selected versus non-selected bottles, either at the peak of the lift phase or during lift movement trajectory. We speculate, therefore, that the systematic positioning differences observed in Experiment 1 are indicators of embodied ownership rather than a preference for one bottle over the other.

We note that the amplitude of the difference between self- and experimenter-owned objects for y at z maximum reported by Constable and colleagues (2011; 2014) for young adults is smaller than that found here. The most plausible explanation is that children's movements are less precise with greater error overall than those of young adults (Goble, Lewis, Hurvitz & Brown, 2005; Schneiberg, Sveistrup, McFadyen, McKinley & Levin, 2002).

The findings raise two theoretical issues. The first is whether motor control processes that can support differentiation between movements directed to self- versus other-owned objects occur during development prior to 24 months. Second, if embodiment does indeed become established in childhood how does it relate to later-developing concepts of ownership?

To deal with the first issue, it is possible that early-established motor control supports the development of self-other boundary differences. Motor control could serve as the foundation for self- versus other-ownership differences. Perinatally, connections are formed between specific body part movements and cognitive-affective outcomes – e.g., obtaining the toy or food item (Bremner Holmes & Spence, 2016; Rochat 1988). Protoimperative pointing gestures and self-reference effects can develop from about 10 months of age, indicating knowledge of the self in relation to locations and objects (Capirci et al., 2005; Pizuto & Capobianco, 2005). In this way, motor experience may promote a self-other dichotomy, subserving embodied ownership described here.

Second, it seems that the self-other dissociation outlined above is in place very early in childhood, in line with the elaboration of cognitions and linguistic markers such as self- versus other-owned property or spatial references referring to specific locations in space (this / that, far /near; Capirci et al., 2005). Capirci et al. (2005) observed that gestures denoting spatial referencing were frequently in place prior to the use of words, or gestures-and-words in combination. Interestingly, in disorders where impaired interaction between the self and others is a core deficit, such as autism (DSM-5; Baron-Cohen, 1989; Hobson, García-Pérez & Lee, 2010) there are also abnormalities in spatial reference gestures (far-near, this-that; Baron-Cohen, 1989; Hobson et al., 2010; see also Attwood, Frith & Hermelin, 1988; Hobson et al., 2010).

In this paradigm, children had ownership of the bottle and were familiar with it for many days prior to completing the task. Ownership is established immediately and conclusively on gifting, and alters cognitive processing of self-owned versus other-owned items (Beggan, 1992). For example, in the self-reference memory effect paradigms, virtual allocation of images of items to self versus other leads to superior recognition of self-related items in adults (Cunningham et al. 2013; Sparks et al, 2016) as well as children (Cunningham, Vergunst, Macrae & Turk, 2013; Sui & Zhou, 2005). Moreover, in the current study, many children also spontaneously said ‘my bottle’ or ‘mine’ when it was revealed during the lifting trials.

In this and prior studies (Constable et al, 2011; 2014), we used familiarity to enhance and ensure the sense of ownership, but it is not clear whether familiarity is a prerequisite for these ownership effects to appear. In unpublished data, where adult participants were gifted an object (mug, placemat) and then performed a task immediately, the results were not so striking as when they take it home and use it, or indeed decorate it (see Constable et al, 2011; 2014). We think this is associated with the idea of expending labour on an object, which in children's studies is shown to be an indicator of ownership (Kanngiesser, Gjersoe, & Hood, 2010). Moreover, children are able to follow the 'history' of a toy, differentiating between their own well-used item and another used or new item (Gelman & Davidson, 2016), so it is also difficult to have them become familiar with one item but do the task with another. One possibility for future experiments is equal exposure to both the child's and the experimenter's bottles during the several days of use at home, with clear instructions that the other bottle does in fact belong to the experimenter.

It is also possible that the children are positioning the experimenter's bottle towards the experimenter seated across from them, rather than positioning it away from themselves. In this paradigm, the experimenter was positioned across from the child to enable hiding the bottles in the black box and reveal them easily prior to lifting trial commencement. In the studies by Constable and colleagues, however, the experimenter was positioned to the right of the adult participants (Constable et al, 2011; 2014), or to the left (experiment 2, Constable et al, 2014). In these studies, the same self-experimenter positioning difference in the y plane as we now report in children. We think that, in the adults, self-owned objects are 'pulled towards the self while other-owned ones are pushed away from the self. Future paradigms could similarly adjust the position of the experimenter, to indicate more clearly whether the effect in children is due to embodiment or a simply positioning close to the owner. Another manipulation may be to use a third, ‘unowned’ bottle, as per the Constable et al studies (Constable et al, 2011; 2014). In those studies, the positioning of the unowned bottle at peak lift tended to occur at a point in the y plane that was between the Self- and Experimenter-owned position. Thus it is unclear whether unowned items are pushed away from the Self, or are not embodied into the Self and thus are not incorporated into a self-other dissociation. Having established the basic pattern of findings, however, the inclusion of neutral bottles may indicate whether these processes are evident in the early childhood stage of development.

We turn now to how this evidence of early embodied ownership fits with the development of other, related concepts such as first possession bias (for example, Friedman, Van de Vondervoort, Defeyter & Neary, 2013) and tracking unique ownership of seemingly identical objects (Gelman et al 2012). It is not clear whether these are different concepts, or exist on a continuum with early embodied ownership. We speculate that early, embodied ownership is continuous with, and even the foundation for, later-developing ownership concepts such as the first possession bias and ownership history. It may be that embodied ownership evokes representations of, and interactions with, objects. The development of later concepts may rely on these representations and interactions. This speculation implies a temporal component: embodied ownerships may manifest initially, then related higher-level conceptualisations of ownership such as self-other differentiation in property rights. To test this, future works needs to test whether embodied ownership actually predicts later developing concepts such as first possession bias and the concept of unique owned objects.

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Figure legends

<u>Figure 1.</u> Individual participants' values for y at z peak lift (the position of the bottle's marker in the y plane at peak lift). The values represent self minus experimenter, and negative numbers represent a bias for positioning own bottles closer to the self. Positive numbers represent a bias for positioning own bottles closer to the experimenter. The red point represents the mean value for the group (-19.08mm) and the green point represents the median value (-46.62mm). For a significant number of children (N = 25 of the 35) children, the number was negative, indicating that overall they positioned their own bottles closer to themselves.

<u>Figure 2.</u> Individual participants' values for y maximum (the maximum deviation of the bottle's marker away from the body in the y plane during the lifting movement's trajectory). The values represent self minus experimenter, and negative numbers represent a bias for positioning own bottles closer to the self. Positive numbers represent a bias for positioning own bottles closer to the experimenter. The red point represents the mean value for the group (-13.36mm) and the green point represents the median value –2.42mm).

<u>Figure 3 panel A.</u> Individual participants' values for y at peak lift (the position of the bottle's marker in the y plane at peak lift) for Experiment 2. The values represent selected minus non-selected bottles, and negative numbers represent a bias for positioning the bottles they selected after task completion closer to the Self. Positive numbers represent a bias for positioning the bottles they selected after task completion closer to the Experimenter. Children did not show a systematic difference in positioning their selected versus non-selected bottle. The red point on the y axis represents the mean value for the group (-4.09mm) and the green point represents the median value (-2.12mm).

Figure 3 panel B. *Individual participants' values for y maximum (the maximum deviation of the bottle's marker away from the body in the y plane during the lifting movement's trajectory) for Experiment 2. The values represent selected minus non-selected bottles, and negative numbers represent a bias for positioning the bottles they selected after task completion closer to the Self. Positive numbers represent a bias for positioning the bottles they selected after task completion closer to the Experimenter. Children did not show a systematic difference in positioning their selected versus non-selected bottle. The red point on the y axis represents the mean value for the group (-1.832mm) and the green point represents the median value 2.195mm).*