Human Movement Science 63 (2019) 138–147

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Brief reaching training with “sticky mittens” in preterm infants: Randomized controlled trial

Andressa Lagoa Nascimento[a], Aline Martins Toledo[b], Leila Foerster Merey[a], Eloisa Tudella[c], Daniele de Almeida Soares-Marangoni[a,*]

[a] Physical Therapy Section, Federal University of Mato Grosso do Sul, Campo Grande, MS, Brazil
[b] School of Physical Therapy, University of Brasilia, Brasilia, DF, Brazil
[c] Departament of Physical Therapy, Federal University of Sao Carlos, Sao Carlos, SP, Brazil

ARTICLE INFO

Keywords:
Infant development
Motor activity
Motor learning
Premature birth

ABSTRACT

Objective: To examine whether a brief reaching training with sticky mittens was effective to improve reaching behavior in newly reaching preterm infants.
Methods: In this randomized controlled trial, twenty four 5-month-old (± 16-week-old corrected age) preterm infants were randomly allocated into experimental or control groups. Infants were assessed three times in a single session: pretraining (immediately before training), posttraining (immediately after training), and retention (4 min after the posttraining). During training, infants in the experimental group wore open fingers Velcro covered mittens. Training consisted of one 4-minute session of stimulated reaching using Velcro covered toys. Controls did not receive the training. During assessments, infants were placed in a baby chair and toys without Velcro were offered at their midline for 2 min. Number of total reaches, proximal adjustments and distal adjustments of reaching were primary outcomes. Grasping was a secondary outcome.
Results: Groups were similar in the pretraining. In the posttraining, trained infants performed greater amount of total reaches and bimanual reaches than untrained infants. Greater amount of bimanual reaches in trained infants was maintained in the retention test. Distal adjustments and grasping outcome were not influenced by the training.
Conclusions: A brief-term training with open fingers sticky mittens benefited reaching behavior and favored retention of increased bimanual reaches in newly reaching late preterm infants. However, it was not sufficient to influence hand openness and early grasping.

1. Introduction

Infants are natural born explorers, always curious about objects around them. Once infants are typically able to reach, at around 3–4 months of age (Berthier & Keen, 2006; Corbetta & Snapp-Childs, 2009; Cunha, Soares, Ferro, & Tudella, 2013; Thelen et al., 1993), opportunities to gather information about objects and learn novel behaviors to act upon them are expanded (Lobo & Galloway, 2013). The development of reaching, therefore, plays an essential role on infants’ further development. However, when biological limitations are present (eg.: alterations in muscle tone, perception-action coupling difficulties, learning impairments, etc.), they can hinder infants’ ability to interact with the world and develop from that. This have been observed in infants born prematurely. For

* Corresponding author at: Universidade Federal de Mato Grosso do Sul, Instituto Integrado de Saúde, Unidade 12 – Fisioterapia, Cidade Universitária, s/n, 79070-900 Campo Grande, MS, Brazil.
E-mail address: daniele.soares@ufms.br (D.d.A. Soares-Marangoni).

https://doi.org/10.1016/j.humov.2018.11.015
Received 11 July 2018; Accepted 28 November 2018
Available online 08 December 2018
0167-9457/

example, late preterm infants (born at 34–36 6/7 weeks of gestation; World Health Organization et al., 2012) present poorer gross motor development at reaching onset and seem to learn less from spontaneous and enhanced reaching experience relative to typically developing infants (Soares, Cunha, & Tudella, 2014). Lack of successful reaching at 4 months corrected age and poor quality of reaching kinematics two months later are related to development of minor neurologic dysfunction (dysfunction in muscle tone regulation, coordination problems, problems in fine manipulative ability, among others) at school age in children born preterm (Fallang, Øien, Hellem, Saugstad, & Hadders-Algra, 2005). Therefore, prematurity can be a determinant of early reaching disorders and later developmental dysfunction. This highlights the essential importance of promoting early reaching interventions for preterm infants.

Growing research has investigated the beneficial effects of early reaching interventions over the past decades (Lobo, Galloway, & Heathcock, 2015). Only a few studies addressed preterm infants, however. These studies have found brief practice of toy-oriented reaching in a single session (Guimarães & Tudella, 2015; Guimarães, Cunha, Mira, & Tudella, 2015; Soares, van Der Kamp, Savelsbergh, & Tudella, 2013) and extended practice over weeks (Heathcock, Lobo, & Galloway, 2008) can enhance reaching behavior in newly reaching preterm infants. These enhancements included increased number of reaches, more functional distal adjustments such as reaching with semi-open hand and increased amount of proximal adjustments, particularly bimanual reaches, after induced practice (training). In general, these findings were attributed to immediate enhancement in infants' perception of objects, which temporarily increased their motivation to act upon them and perform more reaching attempts (Guimarães & Tudella, 2015; Soares et al., 2013), as well as to improvements in infants' understanding of object properties and better muscle performance and motor control of upper limbs, which resulted in the selection of hand patterns adjusted to the task demands (Heathcock et al., 2008). These inferences on the effects of reaching movement experience on preterm infants' reaching have important implications for clinical practice. They provide scientific evidence for immediate and extended enhancement in preterm infants' motor behavior that are commonly observed by therapists after brief and long-term task-specific interventions. These assumptions also relies on theoretical frameworks applied to infant development. According to Gibson (1988, 1986), the infant's perception of objects (eg.: toy position in space and its physical properties) guides the planning and selection of movement patterns so that an action goal is attained. Changes in manual behavior are also driven by the combined interaction between intrinsic constraints (eg.: brain integrity, infant's motivation, upper limb strength and control), extrinsic factors, such as the environment characteristics (eg.: gravity force, amount of stimulus involved, object properties) and the complexity of task demands (eg: reaching at midline, reaching objects held in space) (Kamm, Thelen, & Jensen, 1990; Thelen & Smith, 1994). In addition, the exploration and repetition of primary motor repertoires (eg.: spontaneous arm movements) allows infants to select specific neural activities patterns that will result in successful object-directed movements (Edelman, 1987; Hadders-Algra, 2000). With expanded training, immediate changes in reaching can be consolidated (Karni et al., 1998; Luft & Buitrago, 2005). Therefore, it can be assumed that as infants experience specific toy-oriented behaviors by means of induced practice (training), toy-oriented behaviors may gradually become more elaborated and functional.

Besides task-specific training, the "sticky mittens" paradigm have been extensively used to train infant reaching (Needham, Wiesen, Hejazi, Libertus, & Christopher, 2017; Wiesen, Watkins, & Needham, 2016; Williams, Corbetta, & Guan, 2015; Gerson & Woodward, 2014; Libertus & Landa, 2014; Needham, Barrett, & Peterman, 2002, to cite a few). In this interesting paradigm designed by Needham et al. (2002), pre-reaching infants are encouraged to reach for Velcro covered toys while wearing closed-finger Velcro covered mittens, thus simulating early experience of picking up toys. Studies have found that single brief training or daily 10-minute training enhanced object exploration and/or object engagement in typically developing infants (Gerson & Woodward, 2014; Needham et al., 2002, 2017; Wiesen et al., 2016) and grasping activity in infants at high risk for autism spectrum disorders (Libertus & Landa, 2014). In contrast, studies with open fingers mittens have suggested the toy-mitten sticking does not drive the process of enhancing successful toy contacts in infants (Corbetta, Williams, & Haynes, 2016; Williams et al., 2015). However, it is consensus that direct haptic feedback at hand-toy contact could influence the infants' responses to training (Corbetta et al., 2016; Needham, Wiesen, & Libertus, 2015; Williams et al., 2015). Hence, open fingers sticky mittens could be more informative for learning to reach during active training (Corbetta et al., 2016). Despite years of research on the sticky mittens paradigm, none of those studies investigated infants born preterm.

In this study, we examined the effects of a single 4-minute session of reaching intervention with open fingers sticky mittens in newly reaching late preterm infants. We hypothesized that trained infants would perform higher number of reaches, proximal adjustments, functional distal adjustments (more reaches with semi-open or open hand) and reaches with grasping than untrained infants. In addition, we expected that these improvements would not be retained 4 min later, thus demonstrating the need of continued practice for more lasting motor adaptations. This study explores relevant information on the role of incremental experience on behavioral changes in preterm infants and can be an important contribution for clinicians who are interested in preventing or minimizing delays in manual behavior in this population.

2. Material and methods

2.1. Design overview

This is a randomized controlled trial with balanced parallel groups design. The study was approved by the Ethics Committee of the University (protocol n°. 981.776/2015) and registered in the Brazilian Clinical Trials Registry (protocol n°. 386vfr-2016).

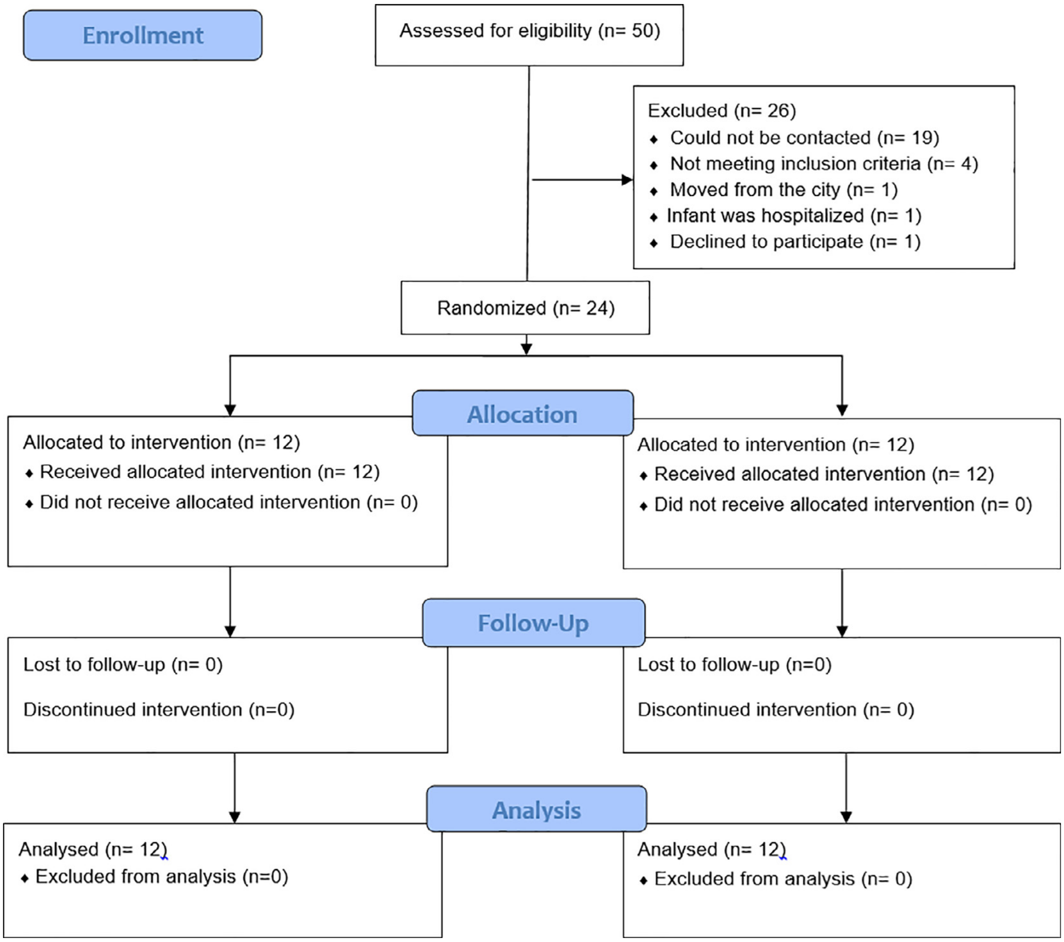

Fig. 1. Flow diagram illustrating sampling procedures.

2.2. Participants

Infants were recruited from the maternity hospital of the Federal University of Mato Grosso do Sul, Brazil, and data was collected at the same University. Sample size calculation (80% power, 95% CI) proposed 8 participants for each group for total number of reaches. First participant was enrolled on February 2016.

Fifty late preterm infants were initially listed. Exclusion criteria included: anoxia, signs of neurological complications, hyperbilirubinemia, congenital malformation, syndromes, sensory dysfunction, cardiopulmonary difficulties, growth restriction. Their weight should be adequate to gestational age (World Health Organization – WHO, 1995). Infants should not be performing more than

Table 1
Characteristics of the sample (mean ± standard deviation) by group.

Characteristic	Experimental group (n = 12)	Control group (n = 12)	p[c]
Gestational age (weeks)	35.86 ± 0.53	36.08 ± 0.48	0.33
Chronological age (weeks)	20.56 ± 0.99	20.28 ± 1.58	0.51
Corrected age (weeks)	16.55 ± 1.09	16.14 ± 1.64	0.48
Weight at birth (kg)	2.53 ± 0.17	2.77 ± 0.31	0.06
Apgar 1st min	8.33 ± 0.82	8.33 ± 0.82	1.00
Apgar 5th min	9.30 ± 0.82	9.40 ± 0.70	0.77
Economic classification (points)[a]	26.40 ± 8.86	31.80 ± 13.13	0.29
AIMS[b] (percentile)	50.00 ± 1.16	50.00 ± 1.57	0.34

[a] Brazilian Economic Classification Criteria indicating mean family income per month from approximately US$880.00 to US$ 1750.00 (ABEP, 2013).
[b] Normative percentile from 25 to 75.
[c] p-Value from ANOVA One-way indicating homogeneous characteristics between groups.

Fig. 2. Training with sticky mittens. (1). The researcher held the toy at the infant's midline and moved the infant's hand toward the toy, at the infant's visual field; (2). The researcher held the toy and the infant's hand close to the toy for a few seconds to allow the infant to touch the toy actively. If the infant did not touch the toy actively, the researcher stimulated the infant's hand with the toy, which stuck to the mitten; (3). The researcher performed tactile stimulation on one upper limb of the infant with the toy and took the toy to the midline to allow the infant to perform active movements of the upper limb toward the toy for a few seconds. When the infant touched the toy, the toy stuck to the mitten. The infant could spontaneously explore the toy for a few seconds. The same activities were performed in the opposite upper limb. (4). Velcro covered mitten and Velcro covered toys used during the training.

three goal-directed reaches in one minute at the first home visit. This assured infants were not skilled reachers.

After the final screening, 24 late preterm infants (M = 35.91 ± 0.62, weeks of gestation) were included (Fig. 1; Table 1). Infants were randomly assigned to the experimental group (n = 12; 7 girls) or the control group (n = 12; 3 girls) (Fig. 1). At the start of their participation (home visits), infants were 4-month-old (12-week-old corrected age) pre-reaching infants. All infants were under maternal care and presented similar socioeconomic status (ABEP, 2013) and adequate gross motor development according to the Alberta Infant Motor Scale (AIMS; Piper & Darrah, 1994). All parents signed informed legal consent.

2.3. Apparatus

Infants were assessed in a baby seat reclined 45° from the horizontal axis. Assessments were recorded using a digital camera (Sony, 60 Hz) positioned antero-laterally to the infant. The dependent variables were coded using the images from the camera in the software ReSpeedr. Randomization was generated using Matlab.

Three small toys covered by "soft" side strips of Velcro were used during the training. Three similar toys were used during assessments, but they were not Velcro covered. The toys ranged from 4 to 6 cm^2 in size and were presented always in the same sequence for all infants. A pair of mittens were constructed from white infant bobby socks. The toe portion was removed and a thumb-hole was created to permit bare fingers and direct haptic contact with the toys (Williams et al., 2015). Both palm and dorsal surfaces of the mittens were covered by "hard" side strips of Velcro (Fig. 2). Each mitten weighted 5 g.

2.4. General procedures

Infant allocation to one of two groups (experimental or control) was performed via computer-generated randomization at the start of the study by an independent researcher. Allocation was concealed from parents and researchers in sequentially numbered, opaque, sealed envelopes. Training was administered to infants by a single researcher. Envelope was unsealed to reveal infant allocation only after the baseline assessment (pretraining). The sequence in which the envelopes were opened was maintained in accordance with the sequence initially defined.

To minimize the influence of spontaneous reaching practice, infants were assessed shortly after the onset of goal-directed reaching. The researcher made home visits once or twice a week to follow up infant reaching from infants' 4-month birthday (12-week-old corrected age). During home visits, infants were placed in the baby seat and toys were offered at their midline at their arms' length. When the infant was able to perform 3–5 reaches in 1 min in a home visit, the actual reaching assessments and intervention protocols were applied. AIMS was applied at the end of this home visit to assess the infant's gross motor development. The AIMS is a valid and reliable tool to assess infant gross motor development from 0 to 18 months (Piper & Darrah, 1994).

2.5. Assessment procedures

All infants were assessed three times: a) immediately before training (pretraining); b) immediately after training (posttraining); c) four minutes after the posttraining (retention test). All infants were assessed under the same conditions. Infants were in diapers or baby bodysuit and were assessed in the baby chair. Only the toys without Velcro were used for the assessments. The researcher, who was positioned in front and out of infant's reaching distance, held one toy at each time. The toy was presented at the infant's midline, xiphoid process height and arm's length, for 2 min (Cunha, Lobo, Kokkoni, Galloway, & Tudella, 2015; Soares et al., 2013; Toledo, Soares, & Tudella, 2011). After each successful hand-toy contact (reach), the toy was gently taken way and presented again. No verbal or physical encouragement was provided for infants during assessments.

2.6. Intervention protocols

Between pretraining and posttraining, the researcher unsealed the next envelope and administered the intervention protocols according to infants' allocation. The infants were positioned on the researcher's lap reclined approximately at 45° (Cunha et al., 2013; Soares et al., 2013) (Fig. 2). All infants received experimental or control conditions according to initial randomization and allocation.

2.6.1. Reaching training with sticky mittens

Only infants in the experimental group received training. The training consisted of stimulated reaching in three activities (Cunha et al., 2013; Cunha, Woollacott, & Tudella, 2013; Soares et al., 2013) as described in Fig. 2. The Velcro covered toys were used to stimulate reaching and infants wore the Velcro covered mittens on both hands during the training. The activities were repeated in a serial sequence in each right (R) and left (L) upper limb [123 (L), 123 (R), −123 (L), 123 (R), 123 (L), 123 (R)] (Fig. 2). This resulted in 6 repetitions over 4 min or in at least 87% of this time. During the remaining time infants were allowed to spontaneously explore the toys.

2.6.2. Control experience

Infants in the control group were placed on the researcher's lap, in the same position as the experimental group, during 4 min. This allowed the same postural experience for both groups. Infants in the control group were allowed to move their upper limbs spontaneously, but no reaching training or tactile stimuli for their upper limbs were provided. The researcher interacted only visually and verbally with the infants, which provided control infants with the same social interaction with the researcher as the experimental group.

2.7. Description of variables and data analysis

Reaching behavior was observed frame by frame using images from the camera in a monitor. A valid reaching consisted of the movement of one or both hands toward the toy resulting in contact, regardless of grasping (Carvalho, Tudella, Caljouw, & Savelsbergh, 2008; Cunha et al., 2013; Cunha et al., 2013; Savelsbergh & Van Der Kamp, 1994; Soares et al., 2013; Toledo et al., 2011). The first frame when the infant started an uninterrupted movement of the hand toward the toy was defined as the beginning of a reach. The end of a reach was defined as the first frame when the infant's hand contacted the toy (Carvalho et al., 2008; Corbetta & Thelen, 1996; Cunha et al., 2013).

Reaching enhancement was the *primary outcome*, measured by the differences in the number of reaches and in the proportions of proximal and distal adjustments of reaching between groups. Grasping enhancement was the *secondary outcome*, measured by differences in the proportions of grasps between groups.

The *number of reaches* was calculated as the total number of valid reaches performed over each 2-min assessment.

Proximal adjustments were coded as *unimanual reach*, when the infant reached for the toy with one hand, resulting in touch (Corbetta & Thelen, 1996; Cunha et al., 2013; Toledo et al., 2011), or *bimanual reach*, when the infant moved both hands simultaneously toward the toy, for at least 50% of the trajectory, with a difference less than or equal to 20 frames, resulting in touch. Only the hand that first touched the toy was considered for the analysis (Corbetta & Thelen, 1996; Cunha et al., 2013; Rocha, Silva, & Tudella, 2006; Toledo et al., 2011).

Distal adjustments were coded considering hand opening at touch: *open hand*, when fingers were completely extended or slightly flexed; *closed hand*, when all fingers were completely flexed, or all fingers were completely flexed but one was extended regardless of extension degree; or *semi-open hand*, when the fingers were in an intermediate position in relation to open and closed hands (Soares et al., 2013).

Grasping outcome consisted of *reaches with grasping*, when the infant "held"/grabbed the toy (or part of it) with the fingers using one or both hands after reaching (Soares et al., 2013; Wimmers, Savelsbergh, van der Kamp, & Hartelman, 1998), or *reaches without grasping*, when the infant reached the toy and did not grab it (Soares et al., 2013).

The analyses were performed by one expert observer blind to the infants' allocation. For coding reliability purposes, all reaches from 4 infants from the sample were coded by two independent observers. Inter-observer reliability assessed by Cohen's Kappa computed considering all variables was 0.86 (95% IC ± 0.01).

2.8. Statistical analysis

The number of reaches was analyzed by frequencies of their occurrence. Proximal and distal adjustments and grasping outcome were analyzed by the proportions of their occurrence in relation to the number of reaches. Significance level α of 0.05 was adopted. Inferential procedures for homogeneity (Levene's test) and normality of variances (Shapiro-Wilk's test) indicated the data was not normally distributed. The Mann-Whitney test was performed to compare groups (experimental and control) in each assessment (pretraining, posttraining, retention). Non-parametric repeated measures ANOVA (Friedman's test) was used to compare assessments. When differences were significant, data were submitted to the Wilcoxon test for multiple comparisons with Bonferroni adjustments. Effect sizes were calculated using r (r = Z-score/√ total sample; $r \leq 0.2$: small effect; $r > 0.2$ and ≤ 0.4: moderate effect; $r \geq 0.5$: high effect).

3. Results

A total of 750 reaches were analyzed. All infants were included in the analyses and received experimental or control conditions as originally allocated.

3.1. Number of reaches

3.1.1. Differences between groups

There was no difference between groups in the total number of reaches at the pretraining ($U(2) = 59.5$, $p = 0.48$, $r = 0.1$). At the posttraining, the experimental group presented greater number of reaches than controls ($U(2) = 25.00$; $p < 0.01$; $r = 0.6$). This difference was not maintained at the retention test ($U(2) = 32.00$; $p = 0.07$; $r = 0.4$) (Fig. 3A).

3.1.2. Differences between assessments

There was a difference in the total number of reaches between assessments in the experimental ($X^2(2) = 17.07$; $p < 0.01$) and the control ($X^2(2) = 7.95$; $p = 0.02$) groups. In the experimental group, the number of reaches increased from the pretraining to the postraining ($p < 0.01$; $r = 0.6$) and decreased from the postraining to the retention test ($p < 0.01$; $r = 0.6$). In the control group, the number of reaches decreased from the postraining to the retention test ($p = 0.01$; $r = 0.5$) (Fig. 3A).

3.2. Proximal adjustments

3.2.1. Differences between groups

There were no differences between groups in the proportions of proximal adjustments at the pretraining ($U(2)$'s < 61.0, p's > 0.48, r's $= 0.1$). At the posttraining, the experimental group presented greater proportion of bimanual reaches than controls ($U(2) = 28.00$; $p = 0.01$; $r = 0.5$). This difference was maintained in the retention test ($U(2) = 21.50$; $p < 0.01$; $r = 0.5$) (Fig. 3B).

3.2.2. Differences between assessments

There was an overall difference in the proportions of proximal adjustments depending on assessment in the experimental group ($X^2(2)$'s $= 18.00$; p's < 0.01). This was characterized by increased number of bimanual reaches from the pretraining to the post-training ($p < 0.01$; $r = 0.6$). This increase was maintained as post hoc analyses with Bonferroni adjustments set at $p < 0.017$ showed no significant difference between posttraining and retention test ($p = 0.05$; $r = 0.4$). There were no differences in the proportions of proximal adjustments in the control group ($X^2(2)$'s $= 1.02$; p's $= 0.60$) (Fig. 3B).

3.3. Distal adjustments

3.3.1. Differences between groups

There were no differences between groups in the proportions of distal adjustments at the pretraining ($U(2)$'s < 66.5, p's > 0.67, r's $= 0.1$) and the posttraining ($U(2)$'s < 70.5, p's > 0.63, r's < 0.2). This result was maintained in the retention test ($U(2)$'s < 49.5, p's > 0.30, r's < 0.3).

3.3.2. Differences between assessments

There were no overall differences in the proportions of distal adjustments depending on assessment in either the experimental ($X^2(2)$'s < 3.08; p's > 0.21) or the control ($X^2(2)$'s < 2.00; p's > 0.37) groups.

3.4. Grasping outcome

There were no differences between groups or between assessments for the proportions of grasping outcomes (Fig. 3C).

4. Discussion

This study investigated the effects of few minutes of reaching training with open fingers sticky mittens in newly reaching late

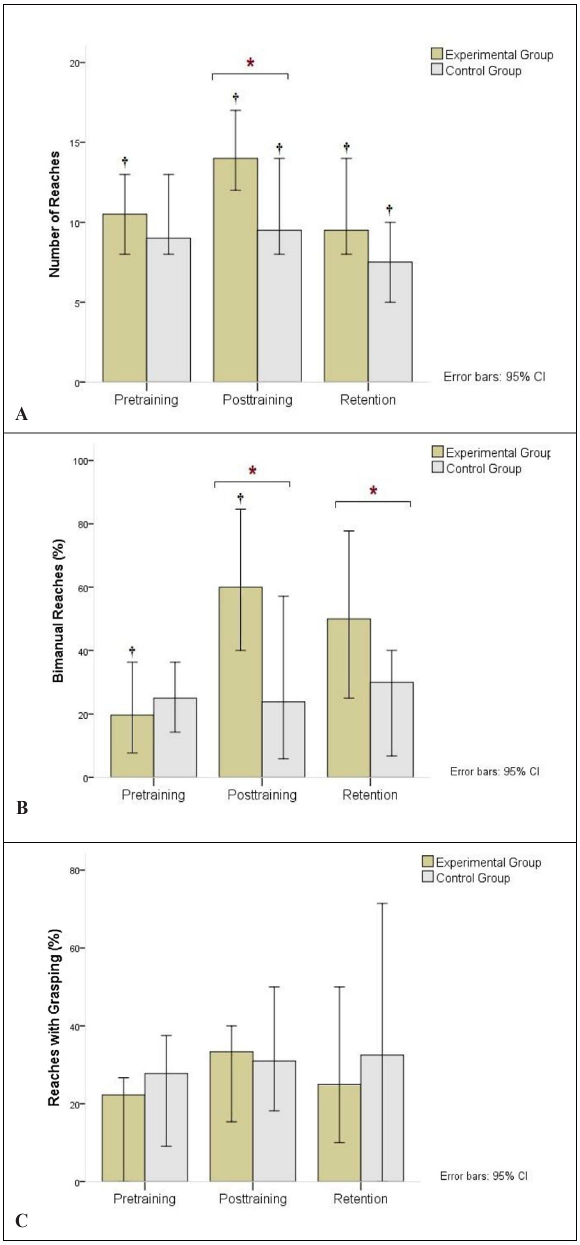

Fig. 3. Median number of total reaches (A). Median proportions of bimanual reaches (B). Median proportions of reaches with grasping (C): Between-groups: U (2)'s < 51.5, p's > 0.22, $r = 0.2$ (pretraining), U (2)'s = 72.00, p's = 1.00, $r = 0.0$ (posttraining), U (2)'s = 57.00, p's = 0.85, $r = 0.1$ (retention); Between-assessments: X^2 (2)'s = 7.13; p's = 0.03 (overall), $p = 0.04$; $r = 0.4$ (pretraining to posttraining), $p = 0.24$; $r = 0.2$ (post-training to retention). * Differences between groups in each assessment ($p < 0.05$). † Differences between assessments in each group ($p < 0.017$). Error bars reflect confidence intervals.

preterm infants. Groups were similar to one another at the start of the study as they presented similar characteristics (see Section 2.2) as well as similar skill level at pretraining.

Our hypothesis that the training would enhance reaching behavior in newly reaching late preterm infants was confirmed. Trained infants reached the toys more times compared to untrained infants, particularly using more bimanual reaches. Training may have motivated these infants to interact more with the toys and explore their available reaching repertoire (Soares et al., 2014, 2013). However, moving the hands against gravity force towards the toys more times may have been a challenging task for these infants. Late preterm infants can present limitations to learn from the environment and are likely to present poorer reaching behavior at reaching onset due to intrinsic constraints associated to their early brain immaturity (Soares et al., 2014), such as lower muscle tonus (Ricci et al., 2008) and poorer upper limb control (Guimarães, Cunha, Soares, & Tudella, 2013). Therefore, our findings show that even brief practice can enhance reaching in late preterm infants and suggest they can overcome these possible limitations in their early reaching behavior associated to prematurity. It is likely that the incremental toy-oriented experience allowed these infants to explore their proximal adjustments repertoire and quickly select more bimanual attempts as a motor adaptation to solve neuromotor problems related to the task performance (Cunha et al., 2015; Karni et al., 1995), such as transporting their hands to the toys to touch them more times successfully.

Our findings of enhanced reaching behavior after a brief reaching training join those from other studies with newly reaching infants (Cunha et al., 2013, 2013, 2015; Needham et al., 2017), particularly preterm infants (Guimarães & Tudella, 2015; Guimarães et al., 2015; Lobo et al., 2015; Soares et al., 2013). In our previous study (Soares et al., 2013), newly reaching late preterm infants who trained toy-oriented reaching for 4 min without mittens or Velcroed toys increased the amount of reaches and bimanual reaches from pre- to post-training. In the study by Needham et al. (2017), typically developing pre-reaching infants who received active training with closed-finger sticky mittens with more auditory feedback in a 10-minute session increased object touching from pre- to posttraining, whereas infants in a passive non-sticky mittens condition decreased this behavior. However, no between-group differences after training were shown in these studies. In contrast, in the present study groups were different after training, which indicates treatment effect. Therefore, we could speculate our open-finger toy-mitten training and the contact with the soft side of the Velcro on the toys provided some advantage in facilitating the infants' reaching in relation to the task practice in itself and the use of closed-finger mittens. Although studies have found no differences between typically developing pre-reaching infants trained with open-finger sticky mittens for 2 weeks and untrained controls, trained infants touched toys covered with the hard ("prickly") side of the Velcro (Corbetta et al., 2016; Williams et al., 2015), which was different from the present study. Therefore, bare fingers contact with the soft Velcro on the toys might have favored our present results. Additionally, we believe the direct haptic contact with objects during the training might have contributed to our findings. As we used these Velcroed toys to provide additional tactile stimuli to the infants' entire upper limbs during the training, this also might have added to the observed effects. These considerations do not provide direct evidence but support the idea that the haptic experience provided by the upper limb-toy contact, but not necessarily toy-mitten sticking, may have facilitated reaching behavior in the present study. Further research will be needed to explore such interpretation directly.

Surprisingly, we found retention of the increased amount of bimanual reaches in the trained infants. Trained infants continued performing more bimanual reaches than untrained infants 4 min after the posttraining. On the other hand, there was no retention of the increased amount of total reaches. In our previous study (Soares et al., 2013), no retention of increased number of total reaches and bimanual reaches 24 h after training was found. We extend those findings by showing that the temporary effects of a brief-term training on the total amount of reaches in late preterm infants disappears much before, only a few minutes following the end of the experience. On the other hand, increased amount of bimanual reaches can last longer, at least up to a few minutes. Possible neuroplasticity mechanisms underlying the present findings will require further research, but as the infant brain is known to be highly responsive to environmental stimuli (Kolb & Gibb, 2011), the enhancement in reaching behavior immediately after a brief-term training could possibly be consistent with initial neuroplasticity. With continuation of the training, initial and fast changes in reaching could be fine-tuned and consolidated (Karni et al., 1998; Luft & Buitrago, 2005). This reinforces the importance of longer and continuous training protocols – as the one proposed by Heathcock et al. (2008) – if one's objective is to favor more lasting motor adaptations for reaching behavior in preterm infants.

Our protocol was not sufficient to enhance the infants' distal adjustments and grasping outcome. In pre-reaching preterm infants, increased amount of reaches with open hand has been found only after a more extended, daily reaching training over 8 weeks, without mittens (Heathcock et al., 2008). Previous studies have suggested that sticky mittens experience can favor grasping activity in 3-month-old typically developing infants (Needham et al., 2002) and infants at high risk for autism (Libertus & Landa, 2014) after 2 weeks of daily closed-fingers sticky mittens experience. Is it likely that infants depend on more than one single session of reaching training with sticky mittens to improve their ability to select motor patterns of the hand adjusted to the properties of the toys and that facilitate grasping. Unlike proximal adjustments, which result from shoulder motion and move the hand close to the midline toy (Bhat, Lee, & Galloway, 2007; Lee, Bhat, Scholz, & Galloway, 2008), fine tune of hand movements are more dependent on elbow control (Bhat et al., 2007). Elbow control requires further movement experience (Konczak & Dichgans, 1997). In addition, reaching a toy in space with successful grasping demands the contraction of the biceps brachii to keep the arm extended against gravity force and contraction of hand and fingers muscles to grab the toy (Smith, Weiss, & Lehmkuhl, 1997; Takei & Seki, 2010). Therefore, this requires the performance of synergic muscle activity in the infants' upper limbs (Toledo et al., 2011). This may be too complex to be performed by late preterm infants when they have just started reaching, especially considering intrinsic constraints that may be typical of late preterm infants in the first months of life, such as lower muscle tonus (Ricci et al., 2008) and difficulties to learn to reach (Soares et al., 2014). Moreover, in the present study infants specifically trained reaching, not grasping. Experiencing primary neuronal repertoires specific to a given task is essential to allow infants to select neural activities patterns that lead to more efficient solutions for the task demands (Edelman, 1987; Hadders-Algra, 2000). A long-term and grasping-specific training would possibly be more efficient to enhance grasping activity after reaching in late preterm infants.

5. Conclusions, clinical implications and limitations

In conclusion, a single 4-minute session of reaching training with open-finger sticky mittens enhanced reaching behavior and favored retention of increased bimanual reaches over at least a short retention period in newly reaching late preterm infants. The direct haptic contact with the soft surface of the Velcroed toys during the training might have potentiated our findings. On the other hand, whilst the training positively influenced reaching, it was not sufficient to enhance hand openness and grasping outcome.

The present training protocol can be applied for clinical practice. Short bouts of incremental movement experience are often used by therapists as part of their within-session strategies to enhance toy-oriented behavior during early interventions. Considering late prematurity is a determinant of early development (Engle, Tomashek, Wallman, & the Committee on Fetus and Newborn, 2007), literature has recommended guided experience exploring toys to minimize possible reaching limitations in late preterm infants (Soares et al., 2013, 2014). Despite these infants frequently do not qualify for early intervention in health care centers, the present training protocol can be taught to parents by therapists. Particularly, therapists could use or recommend this training protocol when aiming at enhancing infants' amount of successful hand-toy contacts, especially with both hands. If the aim is to enhance early grasping, this protocol is not appropriate. We reinforce the importance of more extended training to favor refinement and consolidation of enhanced motor behavior in newly reaching late preterm infants.

One limitation of this study is that our sample may not be representative of the general population of preterm infants. In addition, due to the absence of an additional comparison group of infants trained with non-sticky mittens, we need to caution in our interpretations and recommend further research addressing this topic in preterm infants. Future research could also explore infants' responses in different periods of retention tests.

Declaration of interests

The authors report no declarations of interest.

Funding sources

Study supported by the Foundation to Support the Development of Education, Science and Technology of State of Mato Grosso do Sul (FUNDECT) in partnership with the National Counsel of Technological and Scientific Development (CNPq), Brazil (protocols: 59/300.051/2015; 59/300.347/2015).

Trial registration

Trial registered in the Brazilian Clinical Trials Registry (ReBec) on December 1st, 2015. First participant enrollment on February 15th, 2016. Trial n°. 386vfr-2016. http://www.ensaiosclinicos.gov.br/rg/RBR-386vfr/.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.humov.2018.11.015.

References

Associação Nacional de Empresas de Pesquisa – ABEP. (2013). Critério de classificação econômica Brasil [Brazilian economic classification criteria]. Associação Nacional de Empresas de Pesquisa [National Association of Research Companies – ABEP]; São Paulo.

Berthier, N., & Keen, R. (2006). Development of reaching in infancy. *Experimental Brain Research, 169*, 507–518.

Bhat, A. N., Lee, H. M., & Galloway, J. C. (2007). Toy-oriented changes during early arm movements II: Joint kinematics. *Infant Behavior and Development, 30*, 307–324.

Carvalho, R. P., Tudella, E., Caljouw, S. R., & Savelsbergh, G. J. P. (2008). Early control of reaching: Effects of experience and body orientation. *Infant Behavior and Development, 31*(1), 23–33.

Corbetta, D., & Snapp-Childs, W. (2009). Seeing and touching: The role of sensory-motor experience on the development of infant reaching. *Infant Behavior and Development, 32*, 44–58.

Corbetta, D., & Thelen, E. (1996). The developmental origins of bimanual coordination: A dynamic perspective. *Journal of Experimental Psychology. Human Perception and Performance, 22*(2), 502–522.

Corbetta, D., Williams, J. L., & Haynes, J. M. (2016). Bare fingers, but no obvious influence of "prickly" Velcro! In the absence of parents' encouragement, it is not clear that "sticky mittens" provide an advantage to the process of learning to reach. *Infant Behavior and Development, 42*, 168–178.

Cunha, A. B., Lobo, M. A., Kokkoni, E., Galloway, J. C., & Tudella, E. (2015). Effect of short-term training on reaching behavior in infants: A randomized controlled clinical trial. *Journal of Motor Behavior, 48*(2), 132–142.

Cunha, A. B., Soares, D. A., Ferro, A. M., & Tudella, E. (2013). Effect of training at different body positions on proximal and distal reaching adjustments at the onset of goal-directed reaching: A controlled clinical trial. *Motor Control, 17*, 123–144.

Cunha, A. B., Woollacott, M., & Tudella, E. (2013). Influence of specific training on spatiotemporal parameters at the onset of goal-directed reaching in infants: A controlled clinical trial. *Brazilian Journal of Physical Therapy, 17*(4), 409–417.

Edelman, G. M. (1987). *Neural Darwinism.* New York: Basic Books.

Engle, W. A., Tomashek, K. M., & Wallman, C. the Committee on Fetus and Newborn. (2007). "Late-preterm" infants: A population at risk. *Pediatrics, 120*(6), 1390–1401.

Fallang, B., Øien, I., Hellem, E., Saugstad, O. D., & Hadders-Algra, M. (2005). Quality of reaching and postural control in young preterm infants is related to neuromotor outcome at 6 years. *Pediatric Research, 58*(2), 347–353.

Gerson, S. A., & Woodward, A. L. (2014). Learning from their own actions: The unique effect of producing actions on infants' action understanding. *Child development, 85*, 264–277.

Gibson, J. J. (1986). *The Ecological Approach to Perception.* Hillsdale: Lawrence Erlbaum Associates.

Gibson, E. J. (1988). Exploratory behavior in the development of perceiving, acting, and acquiring of knowledge. *Annual Review of Psychology, 39*, 1–41.

Guimarães, E. L., Cunha, A. B., Mira, D. M., & Tudella, E. (2015). Influence of short-term training on the distal adjustments of reaching in preterm infants. *Journal of Human Growth and Development, 25*(3), 263–270.

Guimarães, E. L., Cunha, A. B., Soares, D. A., & Tudella, E. (2013). Reaching behavior in preterm infants during the first year of life: A systematic review. *Motor Control, 17*(4), 340–354.

Guimarães, E. L., & Tudella, E. (2015). Immediate effect of training at the onset of reaching in preterm infants: Randomized clinical trial. *Journal of Motor Behavior, 47*(6), 535–549.

Hadders-Algra, M. (2000). The Neuronal Group Selection Theory: A framework to explain variation in normal motor development. *Developmental Medicine and Child Neurology, 42*(8), 566–572.

Heathcock, J. C., Lobo, M., & Galloway, J. C. (2008). Movement training advances the emergence of reaching in infants born at less than 33 weeks of gestational age. *Physical Therapy, 88*, 310–322.

Kamm, K., Thelen, E., & Jensen, J. L. (1990). A dynamic systems approach to motor development. *Physical Therapy, 70*, 763–775.

Karni, A., Meyer, G., Jezzard, P., Adams, M., Turner, R., & Ungerleider, L. G. (1995). Functional MRI evidence for adult motor cortex plasticity during motor skill learning. *Nature, 377*, 155–158.

Karni, A., Meyer, G., Rey-Hipolito, C., Jezzard, P., Adams, M. M., Turner, R., & Ungerleider, L. G. (1998). The acquisition of skilled motor performance: Fast and slow experience-driven changes in primary motor cortex. *Proceedings of the National Academy of Sciences of the United States of America, 3, 95*(3), 861–868.

Kolb, B., & Gibb, R. (2011). Brain plasticity and behaviour in the developing brain. *Journal of the Canadian Academy of Child and Adolescent Psychiatry, 20*(4), 265–276.

Konczak, J., & Dichgans, J. (1997). The development toward stereotypic arm kinematics during reaching in the first 3 years of life. *Experimental Brain Research, 117*, 346–354.

Lee, H. M., Bhat, A. N., Scholz, J. P., & Galloway, J. C. (2008). Toy-oriented changes during early arm movements IV: Shoulder-elbow coordination. *Infant Behavior and Development, 31*, 447–469.

Libertus, K., & Landa, R. J. (2014). Scaffolded reaching experiences encourage grasping activity in infants at high risk for autism. *Frontiers in Psychology, 5*(1071), 2014.

Lobo, M. A., & Galloway, J. C. (2013). The onset of reaching significantly impacts how infants explore both objects and their bodies. *Infant Behavior and Development, 36*, 14–24.

Lobo, M. A., Galloway, J. C., & Heathcock, J. C. (2015). Characterization and intervention for upper extremity exploration & reaching behaviors in infancy. *Journal of Hand Therapy, 28*(2), 114–125.

Luft, A. R., & Buitrago, M. M. (2005). Stages of motor skill learning. *Molecular Neurobiology, 32*(3), 205–216.

Needham, A., Barrett, T., & Peterman, K. (2002). A pick me-up for infants' exploratory skills: Early simulated experiences reaching for objects using "sticky mittens" enhances young infants' object exploration skills. *Infant Behavior and Development, 25*, 279–295.

Needham, A. W., Wiesen, S. E., Hejazi, J. N., Libertus, K., & Christopher, C. (2017). Characteristics of brief sticky mittens training that lead to increases in object exploration. *Journal of Experimental Child Psychology, 164*, 209–224.

Needham, A., Wiesen, S., & Libertus, K. (2015). Sticky mittens, prickly Velcro, and infants' transition into independent reaching: Response to Williams, Corbetta, and Guan (2015). *Infant Behavior and Development, 41*, 38–42.

Piper, M. C., & Darrah, J. (1994). *Motor Assessment of the Developing Infant.* Philadelphia, PA: W B Saunders.

Ricci, D., Romeo, D. M., Haataja, L., Van Haastert, I. C., Cesarini, L., Maunu, J., et al. (2008). Neurological examination of preterm infants at term equivalente age. *Early Human Development, 84*(11), 751–761.

Rocha, N. A. C. F., Silva, F. P. S., & Tudella, E. (2006). The impact of object size and rigidity on infant reaching. *Infant Behavior and Development, 29*(2), 251–261.

Savelsbergh, G. J. P., & Van Der Kamp, J. (1994). The effect of body orientation to gravity on early infant reaching. *Journal of Experimental Child Psychology, 58*, 510–528.

Smith, L. K., Weiss, E. L., & Lehmkuhl, L. D. (1997). *Cinesiologia clínica de Brunnstrom [Brunnstrom's clinical kinesiology].* Barueri, Brazil: Editora Manole.

Soares, D. A., Cunha, A. B., & Tudella, E. (2014). Differences between late preterm and full-term infants: Comparing effects of a short bout of practice on early reaching behavior. *Research in Developmental Disabilities, 35*(11), 3096–3107.

Soares, D. A., van Der Kamp, J., Savelsbergh, G. J., & Tudella, E. (2013). The effect of a short bout of practice on reaching behavior in late preterm infants at the onset of reaching: A randomized controlled trial. *Research in Developmental Disabilities, 34*(12), 4546–4558.

Takei, T., & Seki, K. (2010). Spinal interneurons facilitate coactivation of hand muscles during a precision grip task in monkeys. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience, 30*(50), 17041–17050.

Thelen, E., Corbetta, D., Kamm, K., Spencer, J., Schneider, K., & Zernicke, R. F. (1993). The transition to reaching: Mapping intention and intrinsic dynamics. *Child Development, 64*, 1058–1098.

Thelen, E., & Smith, L. B. (1994). *A Dynamic Systems Approach to the Development of Cognition and Action.* Cambridge: MIT Press.

Toledo, A. M., Soares, D. A., & Tudella, E. (2011). Proximal and distal adjustments of reaching behavior in preterm infants. *Journal of Motor Behavior, 43*(2), 137–145.

Wiesen, S. E., Watkins, R. M., & Needham, A. W. (2016). Active motor training has long-term effects on infants' object exploration. *Frontiers in Psychology, 2*, 7–599.

Williams, J. L., Corbetta, D., & Guan, Y. (2015). Learning to reach with "sticky" or "non-sticky" mittens: A tale of developmental trajectories. *Infant Behavior and Development, 38*, 82–96.

Wimmers, R. H., Savelsbergh, G. J., van der Kamp, J., & Hartelman, P. (1998). A developmental transition in prehension modeled as a cusp catastrophe. *Developmental Psychobiology, 32*, 23–35.

World Health Organization – WHO. (1995). Classificação estatística internacional de doenças [International Statistical Classification of Diseases]. 10. rev. São Paulo.

World Health Organization, March of Dimes, PNMCH, & Save the Children (2012). *Born Too Soon: The Global Action Report On Preterm Birth.* Geneva: World Health Organization.