Self-Feeding Kinematics in an Ecological Setting: Typically Developing Children and Children With Cerebral Palsy

Tal Krasovsky, Tal Keren-Capelovitch, Jason Friedman, and Patrice L. Weiss

***Abstract*—Assessment of self-feeding kinematics is seldom performed in an ecological setting. In preparation for development of an instrumented spoon for measurement of self-feeding in children with cerebral palsy (CP), the current work aimed to evaluate upper extremity kinematics of self-feeding in young children with typical development (TD) and a small, age-matched group of children with CP in a familiar setting, while eating with a spoon. *Methods*: Sixty-five TD participants and six children diagnosed with spastic CP, aged 3-9 years, fed themselves while feeding was measured using miniature three-dimensional motion capture sensors (trakStar). Kinematic variables associated with different phases of self-feeding cycle (movement time, curvature, time to peak velocity and smoothness) were compared across age-groups in the TD sample and between TD children and those with CP. *Results*: Significant between-age group differences were identified in movement times, time to peak velocity and curvature. Children with CP demonstrated slower, less smooth self-feeding movements, potentially related to activity limitations. *Conclusions*: The identified kinematic variables form a basis for implementation of self-feeding performance assessment in children of different ages, including those with CP, which can be deployed via an instrumented spoon.**

***Index Terms*—Self-feeding, upper extremity, kinematics, typical development, cerebral palsy.**

I. INTRODUCTION

A CHILD'S self-feeding entails a complex interaction of physiological, biomechanical, and behavioral processes involving performance skills and activity demands [1]. At successive stages of development, typically-developing (TD) children shift from complete dependence for feeding to independent performance [2]. In contrast, children with cerebral palsy (CP) often have difficulties in self feeding including prolonged eating times or grasping the utensil [3]. These difficulties often stem from their inability to maintain the necessary synergistic relationship between stability and mobility [4].

Conventional clinical assessment of self-feeding typically involves performance-based scales and subjective questionnaires [5]. Far less pervasive is the use of objective kinematic characterization of the phases of movement at the level of individual and coordinated joint and limb-segment motion [6], [7]. These variables may be sampled during dynamic daily activities both in dedicated laboratories and functional settings in clinics, schools, and home [5], [8]. Kinematic outcomes are considered criterion standard data for many functional tasks because they provide objective, quantitative support for assessment and clinical decision-making for many clinical populations [9], [10]. When used in conjunction with clinical assessments, these data help identify underlying pathological mechanisms of movement (e.g. gait) and facilitate clinical decision making [11], [12]. Although kinematic analyses of upper extremity tasks have been reported less commonly [7], they have been used to characterize functional tasks such as reaching [13] and grasping [8], and to evaluate and treat handwriting difficulties [14]. The ability to identify self-feeding kinematics in children and the effects of age, self-feeding phase and motor impairment is largely unknown.

Recent technological advancements have enabled the development of instrumented devices which may assist in quantifying healthy and pathological movement in a variety of populations [15], [16]. Aside from obtaining an objective measurement of movement quality, these objects, which include but are not limited to wearable sensors, can assist in rehabilitation intervention planning in children with CP [17]. In order to measure self-feeding kinematics of children in an ecological setting, we have developed an instrumented spoon (DataSpoon; [18]) which measures self-feeding behavior in children during performance of an everyday, functional eating task. Our recent work [19] has demonstrated the feasibility and validity of this device. However, prior to establishing outcome measures which will be relevant for evaluation of self-feeding, it is essential to understand the effect of age (typical development) and neurological status (cerebral palsy)

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on self-feeding kinematics in the different phases of the self-feeding cycle.

Thus, the current study aimed to evaluate the self-feeding kinematics of the dominant upper extremity of young children with typical development and a small sample of young children with spastic CP. Specifically, age- and phase-related changes in self-feeding kinematics were examined in typically developed young children and compared to a small sample of age-matched children with CP.

II. MATERIALS AND METHODS

A. Ethics

Ethical approval for the study was obtained from the University of Haifa Institutional Review Board, approval no. 310/15. A parent signed an informed consent form, and assent was obtained verbally from the children.

B. Participants

A convenience sample of 65 children with typical development (39 boys) aged 3 to 9 years ($M = 6.0$, $SD = 1.75$), and an additional sample of six children (4 boys) with CP, aged 5 to 7 years old (M = 6.0, SD = 0.75) were recruited. Exclusion criteria for the TD group were a history of prematurity, developmental delay, seizures, or neurological diagnoses; none had received occupational or physical therapy prior to the study. Children with CP were classified as Gross Motor Function Classification System-GMFCS I-IV (Palisano *et al.*, 1997), MACS I-III (Eliasson *et al.*, 2006). Children with severe cognitive, vision, or hearing challenges or a history of seizures were excluded from the CP group. Children who were unable to use a spoon were also excluded.

The TD sample was divided into three age groups: Young—children aged 3 to 5 years in junior kindergarten ($n = 22$, 33.8%); Middle—children aged 5 to 7 years in kindergarten ($n = 23$, 35.5%); and Older—children aged 7 to 9 years in Grades 1 to 3 ($n = 20$, 30.8%). Age cut-offs were based on developmental milestones; by the age of 3 years, children with TD can manipulate a spoon; by the age of 5 years, they may use a knife and fork competently; and by age 9, children are expected to master adult-like performance [2]. The children with CP were compared to the middle group, which matched their age.

C. Procedure

Data collection took place in a quiet room located in each child's home in a single 45- to 60-minute session. The child was accompanied by a parent or other familiar adult. The adult completed the demographic questionnaire, and the researcher administered the PEDI to document performance in functional daily skills with or without caregiver assistance. Children in the TD group were seated on a standard child-size chair without armrests (IKEA) facing a sturdy plastic table (48 cm in height). A custom-made placemat, a plastic spoon, and a rimmed plastic plate (all standard issue from IKEA, the colors of which the child could choose) were placed on the table's surface. Children with CP used their best seating position, with the same type of placemat, plate and spoon. The plate contained a mildly sweet pudding (easily scooped onto a spoon) of the child's choice. The placemat was centered to the midline of the child's body. The researcher placed the spoon on the right or left side of the plate according to the child's hand dominance (for TD children) and the less-affected side (for children with CP) and requested that the child eat with the spoon (Figure 1). The researcher provided minimal verbal or physical facilitation, and no instructions were given to the child regarding grip. At the end of the experimental session, the child was rewarded with the spoon and plate set to keep.


[redacted]

Fig. 1. Experimental setup showing the table with the plate and spoon. The sensors were placed on the spoon (B), forearm (C), upper arm (D), and head (E) and located near the transmitter (A).

Before any equipment was attached, the child was requested to eat three or four spoonfuls. The four trakSTAR sensors were then affixed to the designated locations on the spoon and the child's body. The child performed two 1-minute self-feeding trials, separated by 1 minute rest (7-10 eating cycles each). Each trial was initiated by an auditory cue (the Hebrew equivalent of "bon appetite"). A video camera recorded a full frontal view of the child's head, upper body, and food dish throughout all trials.

Following the experimental session, the researcher rated the young children with CP according to the GMFCS and MACS.

D. Instruments

1) Demographic questionnaire. A parent or caregiver completed a demographic questionnaire that included age, sex, and medical and developmental histories.

2) Pediatric Evaluation Disability Inventory (PEDI) evaluates function in children aged 0.5 to 7.5 years. The PEDI measures both functional skills and caregiver assistance in three domains: (1) self-care, (2) mobility, and (3) social function. The PEDI is valid and reliable for healthy children [20] as well as for children with cerebral palsy [21]. Good to excellent interrater reliability and validity have been established for the Hebrew version of the PEDI [22]. In the current work, the self-care domain was assessed both in terms of functional skills and caregiver assistance for all children.

3) The Gross Motor Function Classification System (GMFCS) is a standardized system to classify gross motor function of children with CP. GMFCS levels range from level I (the child is able to walk and run, but has some difficulty with more advanced skills) to level V (the child has very limited voluntary movement ability) [23].

4) Manual Abilities Classification System (MACS) [24] MACS describes how children with CP use their hands to handle objects in daily activities using five levels, based on the self-initiated ability and the need for assistance/adaptation to perform manual activities in everyday life [24].

5) Motion capture (trakSTAR) (Ascension Technology, 2014). TrakSTAR is an electromagnetic tracker designed for short-range motion tracking applications. TrakSTAR was used to record kinematic data using four miniature cylindrical sensors (2.0 mm (outer diameter) X 9.9 mm (length)) which were attached to the participant's upper extremity (dorsal side of the forearm midway between the elbow and wrist, lateral side of upper arm midway between the shoulder and elbow, midline of the forehead and the distal side of a standard plastic spoon. These sensors tracked position and orientation with six degrees of freedom consisting of pitch, yaw, roll, and X-, Y-, and Z-coordinates. The data were sampled at 240Hz to a host computer and filtered with a two-way, fourth-order, low-pass Butterworth filter (3 Hz cut-off frequency).

6) Eating Cycle Identification Routine

The self-feeding cycle start and end points were identified via a custom, semi-automated algorithm using MATLAB (MathWorks, Inc., 2010; https://www.mathworks.com/).

The beginning and end of each self-feeding cycle were manually determined by two expert occupational therapists. Reliability of manual identification was determined for nine kinematic variables sampled during two successive self-feeding trials (6–10 eating cycles each) and intraclass-correlation coefficients ($ICC_{(3,1)}$) ranged from 0.77 to 0.99 (95% CI), showing moderate-to-excellent inter-rater reliability. Then, each cycle was divided into three phases (In plate, Transport-up, and Transport-down) based on data from the spoon sensor's tangential velocity and Z-axis (up–down) orientation, which were a-priori suggested to represent kinematics of the different phases. For more information on the identification process - see appendix.

E. Kinematic Variables

The kinematic variables were computed from the spoon sensor (except for the head translation which was based on the head sensor) and defined in the following manner:

Total cycle time (*s*). The duration in seconds from the beginning to the end of the eating cycle.

Time in plate, Transport up time, Transport down time (s). The respective durations of the three phases of the self-feeding cycle. Transport up time included also the time in mouth.

Number of peaks in the tangential velocity profile (*N*): Tangential velocity was defined as the square root of the sum of squared velocities for the three movement axes. The number of peaks in the tangential velocity profile was counted throughout the self-feeding cycle, representing zero-crossings in the acceleration profile, and a proxy for measuring movement smoothness [25].

Percent time to peak velocity transport-up and down (%). The percent of the transport-up and transport-down times required to reach the peak tangential velocity.

Movement curvature up and down (ratio). The 3D path of the spoon from the plate to the mouth and back was defined separately for the transport up and transport down phases as the total 3D path length divided by the straight-line distance from the plate (lowest Z-axis point) to the mouth (highest Z-axis point). Higher values denote a more curved path.

TABLE I

CHARACTERISTICS OF TYPICALLY-DEVELOPING CHILDREN IN THE THREE AGE GROUPS

	Young (n=22)	Middle (n=23)	Older (n=20)
Sex (M/F)	14M / 8F	12M / 11F	13M / 7F
Hand used for eating (L/R)	1L /21R	3L /20R	1L /19R
Age (years) (mean (SD))	4.25 (0.6)	5.67 (0.47)	8.25 (0.81)
PEDI functional skills (self-care) (mean (SD))	78 (9)	83 (7)	97 (6)
PEDI caregiver assistance (self-care) (mean (SD))	79 (12)	82 (10)	96 (7)

Head translation anteroposterior (mm). The ROM of the head in the anteroposterior direction from the beginning of the eating cycle to the end of the transport up phase.

F. Data Analysis

Normality was assessed using the Shapiro-Wilk test. For normally distributed variables, analysis of variance (ANOVA) and Bonferroni post-hoc testing were used to test the effect of age (between-subject variable) on self-feeding kinematics. Three kinematic variables were measured during both *Transport-up* (spoon from plate to mouth) and *Transport-down* (spoon from mouth to plate) phases of movement. For these variables, in the case of the normally distributed variables, mixed-design ANOVA were used to test the effects of age and phase. For non-normally distributed kinematic variables, Kruskal-Wallis and Mann-Whitney U tests (with Bonferroni correction for significance level) were applied to determine the effect of age, and Wilcoxon rank-sum tests were used to examine the effect of movement phase where appropriate. Non-parametric Mann-Whitney tests were used to assess differences between the groups (TD, CP). Significance was set at $p < .05$ and a Bonferroni correction was used.

III. RESULTS

Characteristics of children in the three age groups (age, sex, hand used for eating, PEDI scores) are described in Table I.

The self-feeding cycle was divided into three phases (*Time-in-plate, Transport-up*, and *Transport-down*). The total cycle time for all TD participants ranged from 1.8 to 8.6s ($M = 3.8$s, $SD \pm 1.4$). Figure 2 describes examples for velocity profiles of typical children for the three TD age groups and the CP group, divided according to self-feeding phases, and Figure 3 shows data points for all study participants (TD, CP) for six selected self-feeding variables with vertical dashed lines separating the data points into the three age categories (Young, Middle, and Older); the means and SDs are shown for each age group in TD children.

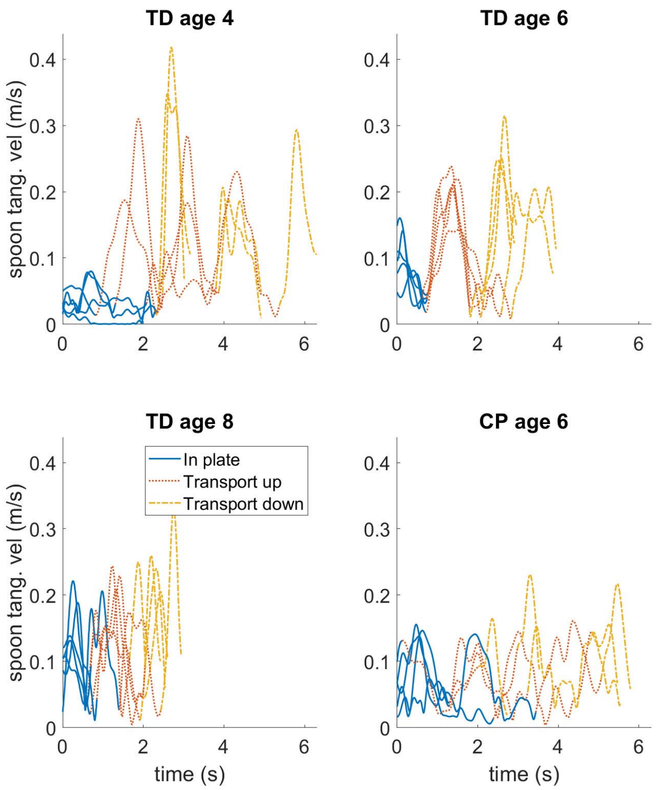

Fig. 2. Velocity profiles of self-feeding for three representative typically-developing (TD) children from the three age groups and one representative child with cerebral palsy (CP). The five middle repetitions are shown for each participant. The different phases of the feeding cycles are denoted using dash and color.

TABLE II
KINEMATIC VARIABLES OF TYPICALLY DEVELOPING CHILDREN BY AGE GROUP

Kinematic variable	Age group Young ($n = 22$)	 Middle ($n = 23$)	 Older ($n = 20$)
Total cycle time (s)*	3.89 [1.68]	3.23 [1.53]	3.23 [1.32]
Time in plate (s)	1.34 [0.83]	1.07 [0.98]	0.96 [0.64]
Transport up time (s)*	1.67 [0.63]	1.30 [0.47]	1.30 [0.44]
Transport down time (s)	0.92 [0.43]	0.76 [0.37]	0.87 [0.63]
Number of peaks in tangential velocity (n)	6.72 [3.16]	5.44 [2.84]	5.5 [2.67]
Percent time to peak velocity up (%) *, ψ	35.76 (11.31)	43.75 (8.40)	44.32 (12.15)
Percent time to peak velocity down (%) *, ψ	52.74 (10.73)	52.86 (9.52)	62.43 (8.75)
Movement curvature up (ratio) *	1.32 [0.28]	1.19 [0.15]	1.22 [0.11]
Movement curvature down (ratio) *	1.22 [0.18]	1.18 [0.18]	1.27 [0.33]
Head translation anteroposterior (mm)	59.3 (30.7)	49.2 (24.1)	53.9 (31.5)

For normally distributed variables, means are reported with standard deviations in brackets. For non-normally distributed variables, medians are reported with inter quartile range (IQR) in square brackets. *= *Significant effect of age;* ψ=*significant effect of phase*.

A. Effect of Age on Kinematic Variables for TD Children

Table II presents kinematic variables for each of the three age groups in the TD children. Significant age-related differences were found for *Total cycle time*, χ^2 (2) = 7.47, $p = .02$. The young group had significantly longer cycle times than the older group ($U = 124$; $p = 0.016$), while differences between the young and middle group were marginally significant ($U = 152$; $p = 0.022$, this difference did not pass the Bonferroni correction). Similarly, age-related differences were identified in *Transport up time*, χ^2 (2) = 17.3, p < 0.001, where the young group took longer to perform the movement up than both the middle (U = 112; p = 0.001) and older group (U = 63; p < 0.001). No age effects were noted for *Transport down time* or *Time in plate*.

Movement curvature varied by age both for movement up (χ^2(2) = 10.00, p = 0.007) and for movement down (χ^2 (2) = 6.04, p = 0.049). For *movement curvature up,* movement of the young children was more curved than that of children in the middle (U = 138, p = 0.009) and the older (U = 107, p = 0.004) age groups. However, for *movement curvature down*, children in the older group moved with higher curvature than children in the middle group (U = 125, p = 0.011) and no other significant differences were found.

With regard to *Percent time to peak velocity*, a significant main effect was found for age, F (2,62) = 10.38, $p = .001$, $\eta^2 = 0.251$). The young and middle groups had significantly shorter *Percent time to peak velocity* compared to the Older group (p = .040), as determined by Bonferroni-corrected

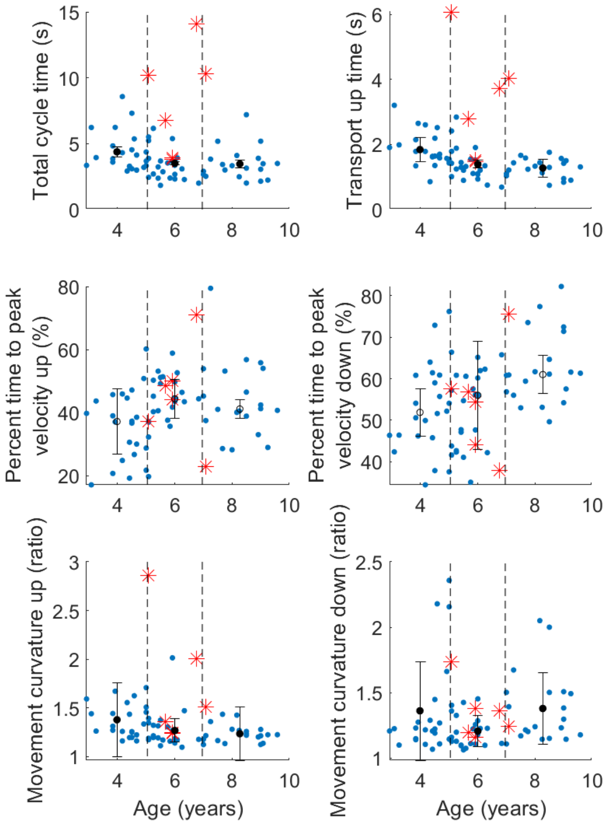

Fig. 3. Data points for all subjects for selected self-feeding variables, with vertical dashed lines separating the data points into the three age categories. Mean values (across repetitions) for typically developing children are shown in blue, red asterisks show children with CP. The hollow black circles and error bars indicate mean and standard deviation, while the filled black circles and error bars indicate median and 25% / 75% quantiles (when the data are not normally distributed – see Table II).

TABLE III
CHARACTERISTICS OF CHILDREN WITH CEREBRAL PALSY (N = 6)

SEX	AGE	HAND	PEDI FS	PEDI CGA	GMFCS	MACS
F	5.7	R	54.3	54.6	3	2
F	7.1	R	51.0	52.3	4	3
M	5.9	R	63.9	56.8	3	1
M	5.9	L	63.9	56.8	3	1
M	6.8	L	50.3	45.9	4	2
M	3.8	R	51.0	56.2	3	2

PEDI FS, PEDI CGA = Scaled scores for PEDI self-care domain under Functional Skills and Caregiver Assistance sections of the Pediatric Evaluation of Disability Inventory (PEDI). Hand=hand used for eating.

TABLE IV
KINEMATIC VARIABLES: DIFFERENCES BETWEEN GROUPS OF CHILDREN WITH CEREBRAL PALSY AND WITH TYPICAL DEVELOPMENT

	Cerebral Palsy (N=6)		Typically-developing (N=23)		
	Median	*IQR*	*Median*	*IQR*	*p-value*
Total cycle time (s)	8.48	7.35	3.23	1.53	**0.001**
Time in plate (s)	2.46	3.64	1.07	0.98	**0.002**
Transport-up time (s)	3.25	3.02	1.30	0.47	**0.002**
Transport-down time (s)	1.51	0.98	0.76	0.37	0.036
Number of peaks in tangential velocity (n)	12.05	12.78	5.44	2.84	**<0.001**
Percent time to peak velocity transport-up (%)	46.39	21.64	44.41	12.67	NS
Percent time to peak velocity transport-down (%)	55.54	19.6	55.99	18.17	NS
Movement curvature up (ratio)	1.43	0.97	1.19	0.15	0.014
Movement curvature down (ratio)	1.30	0.29	1.18	0.18	NS
Head translation anteroposterior (mm)	42.23	25.31	55.86	40.65	NS

Bold=comparisons pass Bonferroni correction for significance (p<0.005)

post-hoc tests. In addition, a significant main effect was found for phase, $F(1{,}62) = 56.75$, $p = .001$, $\eta_p^2 = 0.478$), such that *Percent time to peak velocity transport-down* was longer for all age groups than was *Percent time to peak velocity transport-up*. No significant age-phase interactions were found $F(2{,}62) = 2.15$, $p = .125$, $\eta_p^2 = 0.065$).

B. Comparisons Between TD Children and Children With CP for Kinematic Variables

The CP group were aged 5 to 7 years, with $M \pm SD = 6 \pm 0.75$ years. All children in the CP group had spastic CP with total body involvement, attended special education schools, and received standard care as appropriate within the school. All children were familiar with self feeding and practiced it at school and home to the best of their ability. Children in the CP group were compared to all TD children from the middle age group (n = 23). Characteristics for children in the CP group are presented in Table III and the kinematic comparison between the groups is presented in Table IV. Significant differences were found for *Total cycle time*, *Transport up time*, *Transport down time*, *Time in plate* and *Number of peaks in tangential velocity* (Table IV). These differences indicated that children with CP took longer to perform the self-feeding task. Furthermore, children with CP moved less smoothly, i.e. with more tangential velocity peaks. The association between activity limitations (PEDI scores) and self-feeding kinematics is described in Figure 4 (no statistical tests were performed given the small sample size.

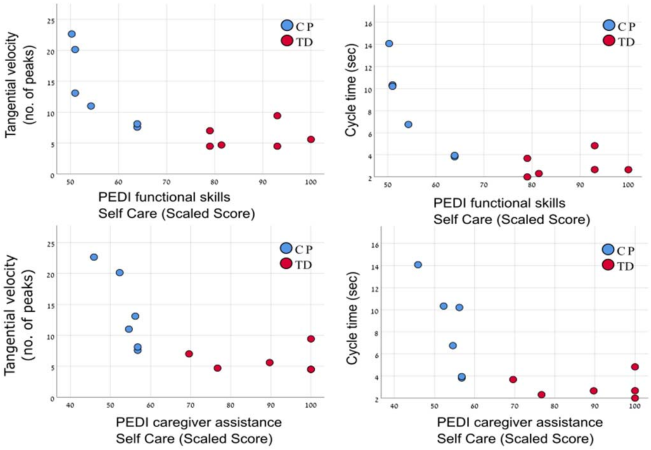

Fig. 4. Kinematic variables and scores on the Pediatric Evaluation Disability Inventory for N = 6 children with CP and N = 6 age- and gender-matched TD children. PEDI scores are scores for the Self-care domain (functional skills and caregiver assistance).

IV. DISCUSSION

This work evaluated age-related changes in self-feeding kinematics and compared self-feeding in TD children with that of a small group of children with CP. Our results demonstrated specific spatiotemporal variables associated with maturation of self-feeding, which seem to stabilize by the age of 5 years (movement time, transport up time, movement curvature) or continue to change also for children by the age of 9 (time to peak velocity). Other variables (smoothness) remained similar across age groups. Our results further suggest that CP-related alterations in self-feeding kinematics may involve different variables (movement time, smoothness) age-related differences.

Clinicians typically evaluate self-feeding ability by monitoring children as they eat, supplementing these observations with clinical assessments, which provide information about whether children are able to eat independently and, if not, the amount of assistance they require [20]. Although these observations can be easily performed in the child's familiar setting, such tools are subjective in nature and provide little insight into solutions for maladaptive eating patterns [5]. Kinematic analyses provide objective, quantitative data that demonstrate key relationships between performance and function and enable more accurate identification of changes over time. Although studies have reported on the maturation of upper-limb kinematics, specifically reach-to grasp tasks, in a laboratory setting [26]–[28], studies evaluating the kinematics of self-feeding in children with motor impairments in an ecological setting (e.g. while eating real food in a familiar environment) are surprisingly scarce. The current work attempted to provide TD and CP children with conditions as similar as possible to their everyday surroundings, since these conditions will be those which will be encountered in future instrumented assessments of self-feeding [18], [19]. Furthermore, kinematic measurement recorded via objects such as instrumented spoons may provide assessment of movement remotely. Existing telehealth applications are often limited in their ability to accurately assess movement quality, specifically in children [29]. Thus, kinematic analysis of self-feeding may be a valuable addition to existing measures of movement quality.

Our results suggest, as other studies have [28], that movement duration and movement curvature both diminish with age. Our results further suggest that these changes are specific to the transport up phase of self-feeding, in contrast with lowering the spoon. Indeed, the transport up phase is characterized by significant accuracy requirements, needed to guide the spoon to reach and enter the rather small target of an open mouth. In contrast, returning the spoon to the plate involves a much larger target and therefore may be accomplished faster (i.e., it may be a type of speed–accuracy trade-off; [30]) and may not demonstrate age-related improvements. Indeed, Gilliaux *et al.* [26] suggested that more complex manual performance requires longer duration, and Simon-Martinez *et al.* [28] similarly demonstrated decreases in movement duration within the same age ranges.

The relatively earlier time to peak velocity while lifting the spoon in the younger children is likely a result of a greater use of real-time feedback. Similar results have been observed in reach-to-grasp tasks, where the relative time to peak velocity increases with age [31]. The younger children are likely less able to accurately plan their movements, thus make more use of a feedback strategy to guide the spoon to the mouth, resulting in a shorter duration initial movement, followed by more corrective movements, as observed by a greater number of peaks in the tangential velocity profile.

The decreases in movement curvature while transporting the spoon to the mouth demonstrated in the current study can be further associated with delayed development in postural control strategies necessary to perform accurate and more efficient trajectories. Thelen and Smith [32] emphasized that stability may develop with children exploring alternative motor strategies, such that by about 10 years they select a strategy to perform manual precision tasks in an adult-like manner. Dusing [33] also emphasized that differences in deviation from an expected path of movement in early development may be reflective of the learning process. Because infants and young children with typical development progress in their ability to coordinate sensory, motor, and postural control systems, ongoing experience with tasks such as reaching and self-feeding, gained as a child ages, appears to improve motor coordination [34], [35].

Finally, this study demonstrated significantly poorer performance during self-feeding by the six children with CP compared to typically developing children for several kinematic variables. These results are in agreement with previous studies. [36], [37] performed in a laboratory setting. Between-group differences may be attributed, in part, to the difficulty in movement and postural control for children with CP who have challenges maintaining the necessary synergistic relationship between core stability and limb mobility, as well as impairment of the sensory processing needed to perform a functional upper extremity task such as self-feeding [4], [38], [39]. Furthermore, these kinematic measures may be related to everyday function in children with CP (cf. Figure 4). Although these results are based on a small sample, they agree with those of van der Heide *et al.* [40] who demonstrated relationships between PEDI domains and reaching kinematics in a laboratory setting. It should be noted that this task was not novel to them and was practiced by the children in the CP cohort both at home and at school. Thus, these results may support use of temporal (duration) and spatiotemporal (smoothness) kinematic variables for future instrumented investigations of self-feeding in an ecological setting for children with CP.

No significant differences (following multiple comparison correction) were observed between the groups in measures related to the movement returning the spoon to the bowl. This may partially stem from the different accuracy requirements of different parts of the cycle. In addition, no significant differences between groups were noted in spatial variables (i.e., movement curvature) or in the temporal structure of the velocity profile (*Percent time to peak velocity*), and no apparent relationship was noted between these variables and activity limitations PEDI. These results partially agree with those of van Der Heide *et al.* [40], who compared reaching kinematics in TD children and those with CP across 3 age groups (2-11 years of age) and demonstrated, similar to the current work, that children with CP made slower and less smooth reaching movements which were also more curved (in contrast with the current work). Reaching towards a target (at arms' length), as was done in the study of van Der Heide *et al.* [40] may differ in its requirements than movement of a spoon filled with food towards the mouth. Indeed, results comparing different movement patterns such as hand-to-mouth, hand-to-head and reach-to-grasp between children with CP with varying levels of hand function, showed that these tasks differ in their ability to differentiate between different levels of severity when analyzing movement curvature/straightness [36]. However, the current results support the link between movement kinematics and activity limitations in children with CP. Similar to other movements, such as handwriting [41] and walking [12], for upper limb function in cerebral palsy, the addition of kinematics to clinical assessment may expose additional facets of motor impairment and movement limitation [36].

A. Study Limitations

The current work has several limitations. The trakStar may have encumbered the children's movements somewhat during data collection. For that reason, we chose to use only four miniature sensors and taped the sensors securely to the body; whereas additional sensors would have yielded more information (e.g., food intake and scooping food as variables separate from Time in plate), they may have led to greater encumbrance. We did not collect data on the participants' postural stability during self-feeding, nor measure their in-hand manipulation and pressure on the spoon. Future work will

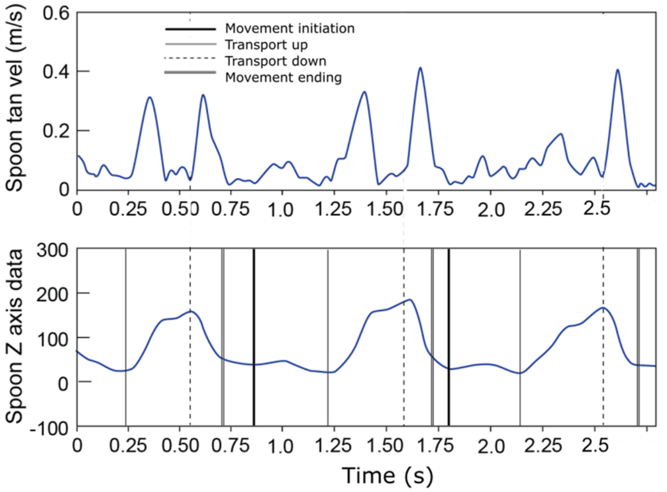

Fig. 5. An example for the visual identification of kinematic variables using tangential velocity and vertical position of the spoon.

require exploration of a larger sample of young children with CP, increasing the participant's age range and measuring self-feeding using more than one food type.

B. Conclusion

This study demonstrates age-dependent differences in key variables associated with self-feeding kinematics, and the differences in a small group of children with CP. The fact that these differences in self-feeding performance were identified under dynamic, real-life conditions, supports the validity of measuring self-feeding kinematics in healthy children and in children with cerebral palsy under these conditions. This approach has the potential to guide clinical intervention for children with difficulties in a range of daily activities by providing objective feedback to children and systematic documentation of progress.

APPENDIX

This section provides details regarding identification of self-feeding phases by clinicians and its reliability.

A. Identification Process

Two experienced pediatric occupational therapists (each with 25 years of experience) performed identification of self-feeding cycles using a custom-written MATLAB program in a semi-automated manner, i.e. start and end of the cycle were identified by the therapists and the transition from transport up to transport down was performed automatically. For each trial, clinicians were presented with graphic representations of the landmark position of the spoon and its tangential velocity profile (Figure 5). The beginning and end of each self-feeding movement were identified as local minima in the vertical position of the spoon. The transition from transport up to transport down was detected automatically as the peak of the vertical position, which precedes the rise in tangential velocity (Figure 5). Kinematic variables (section E) were then calculated in MATLAB based on these timings.

Together with manual identification, clinicians watched videos of the session and excluded trials according to the following occurrences: a *double dip* (dipping the spoon more than once in the food before the end of the eating cycle), *double bite* (clearing the food from the spoon in the mouth more than once before the end of the eating cycle), *external disruption* (disruption of the child's eating cycle initiated by the researcher or parent, such as inadvertent speaking to or touching the child during data collection), or *internal disruption* (disruption of the eating cycle initiated by the child such as playing with the spoon, when the child spoke or touched the researcher or parent, or did not cooperate). In total, ∼5% of all trials were discarded.

B. Reliability

Test–retest reliability was determined by calculating intra-class correlation coefficients (ICC(3,1)) between two successive self-feeding trials (7–10 eating cycles each) separated by 1 minute, on a random sample of 10 participants. ICCs ranged from 0.81 (95%CI 0.58-0.92) for percent time to peak velocity down, to 0.99 (95%CI 0.98-0.99) for Number of peaks in the tangential velocity profile, indicating excellent test-retest reliability for all measured variables.

Inter-rater reliability was determined by calculating intra-class correlation coefficients (ICC(3,1)) between two successive self-feeding trials (7–10 eating cycles each) separated by 1 minute, for a random sample of 10 participants. ICCs ranged from 0.77 (95%CI 0.41-0.90) for movement curvature up to 0.99 (95%CI 0.57-0.93) for percent time to peak velocity transport down, suggesting moderate to excellent inter-rater reliability for all measured variables.

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