Kinematics of Motor Control in Autism Spectrum Disorder:
An Exploratory Analysis of Goal-Directed Finger Movements during Smart-tablet Gameplay

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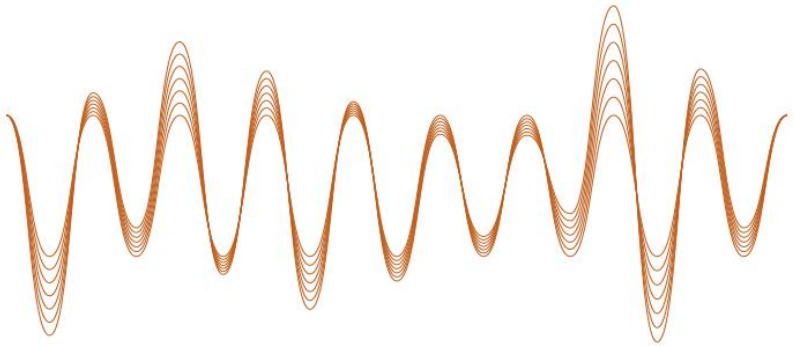
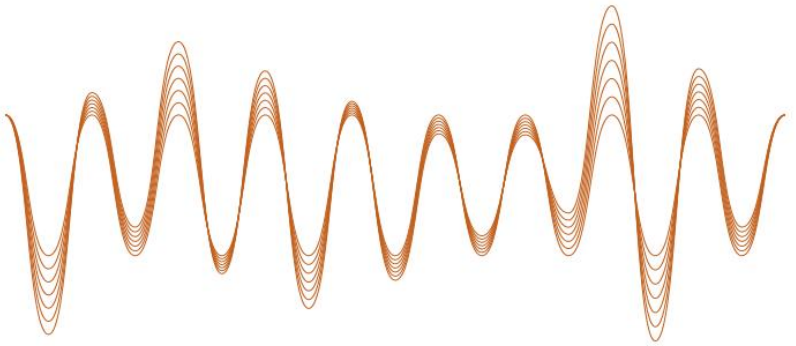
The motor system optimises movements to achieve goals



Biological noise

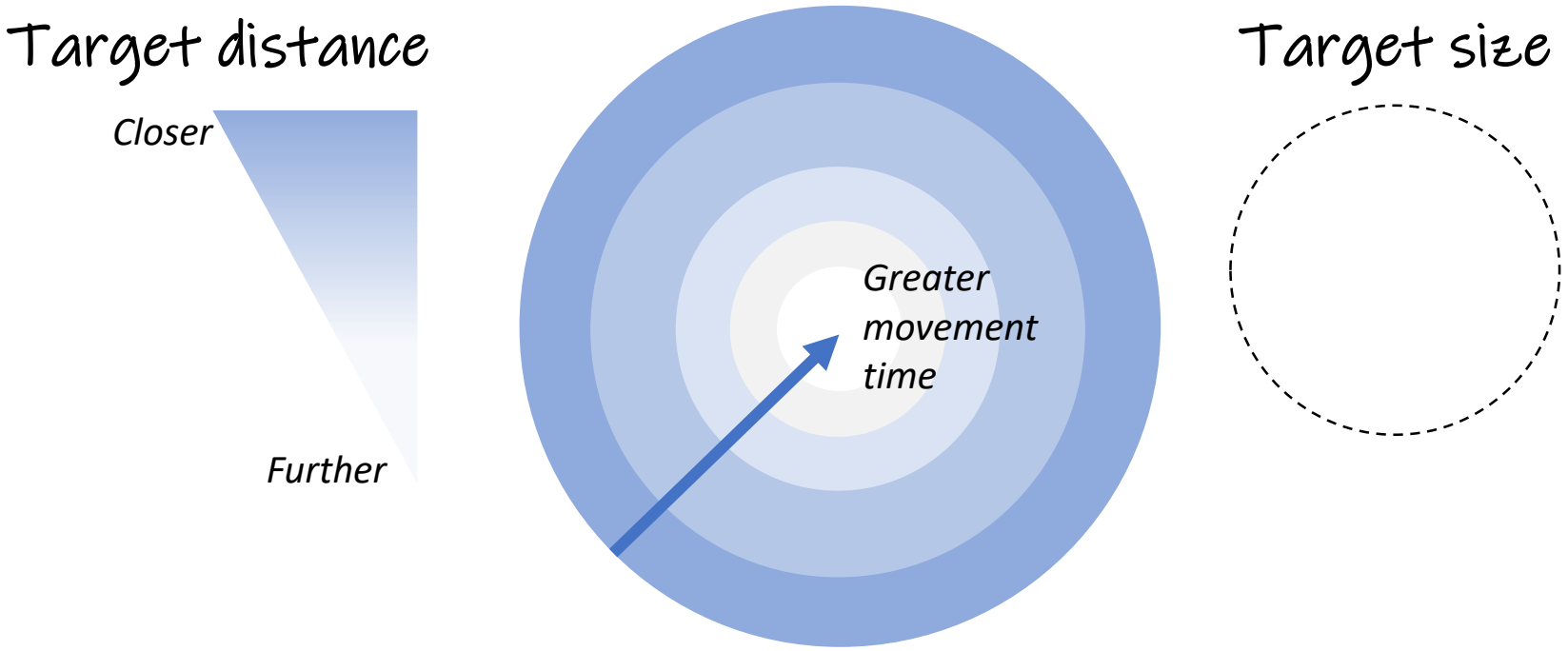


Environmental noise

(Harris & Wolpert, 1998)

Fitts Law

Further and smaller targets require greater movement time



(Fitts, 1954)

Motor control of goal directed movements

EARLY PHASE

- **Feedforward control:**
  pre-specified command to produce the desired output (eg. Distance, force)

- **Forward model:**
  predicted new state after the motor command

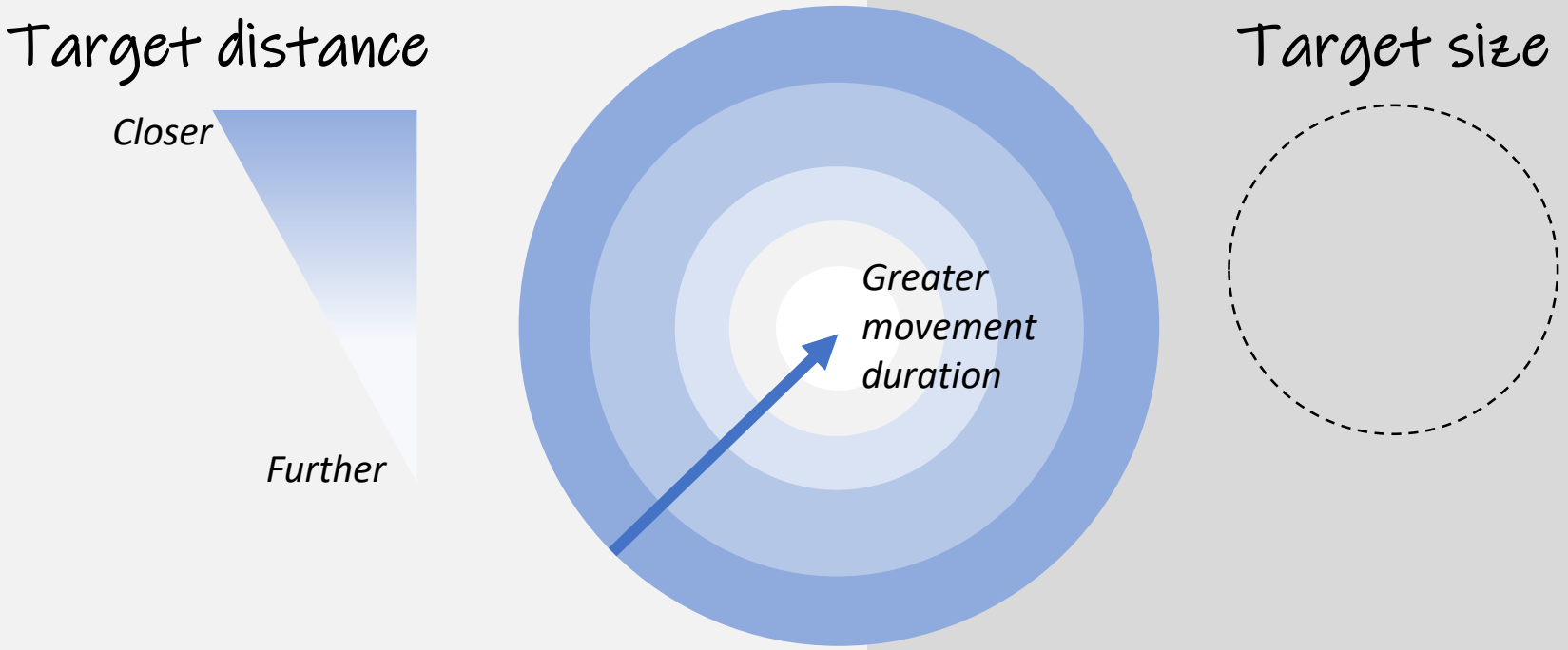
LATE PHASE

- **Sensory feedback control:**
  Commands based on delayed sensory information of the new motor state

Duration of movement

(Woodworth, 1899)
(Meyer et al., 1988)
(Elliott et al., 2010)

Dissociable effects of target distance and target size



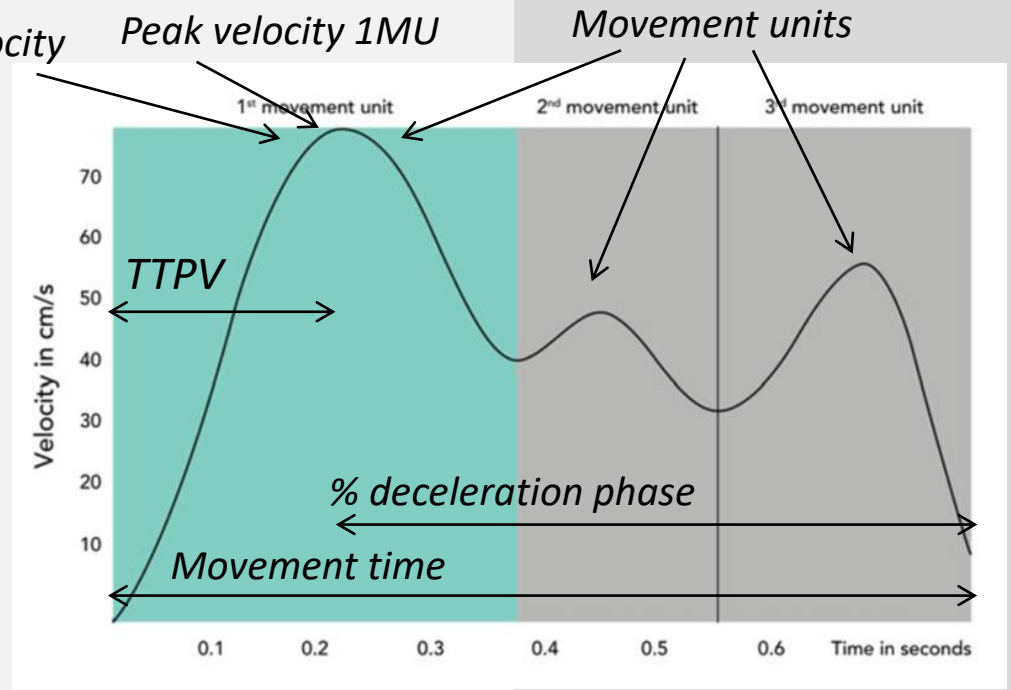
(MacKenzie, 1987)
(Bootsma et al., 2004)

Movement kinematics can reflect feedforward and feedback control processes

EARLY PHASE

Feedforward + Forward model

- **Peak velocity**
- **Time to peak velocity**
- **Peak velocity 1MU (First Movement Unit)**



LATE PHASE

Sensory Feedback

- **Movement units**
- **% deceleration phase**

EARLY and LATE

- **Movement time**

Figure from Gottwald et al. (2017)

Is the kinematics of motor control different in autism spectrum disorder?

EARLY PHASE

Feedforward + Forward model

- **Lower peak velocity?**
- **Longer time to peak velocity?**
- Peak velocity 1MU

N ~ 25
N < 40

Different tasks

Earlier Studies

LATE PHASE

Sensory Feedback

- **Greater Movement units?**
- % deceleration phase

EARLY and LATE

- **Longer movement time?**

(Campione et al., 2016, Cook et al., 2013; Dowd et al., 2012; Forti et al., 2011; Glazebrook et al., 2006; Mari et al., 2003; Stoit et al., 2013; Yang et al., 2014)

Data

Data: from Anzulewicz et al (2016)

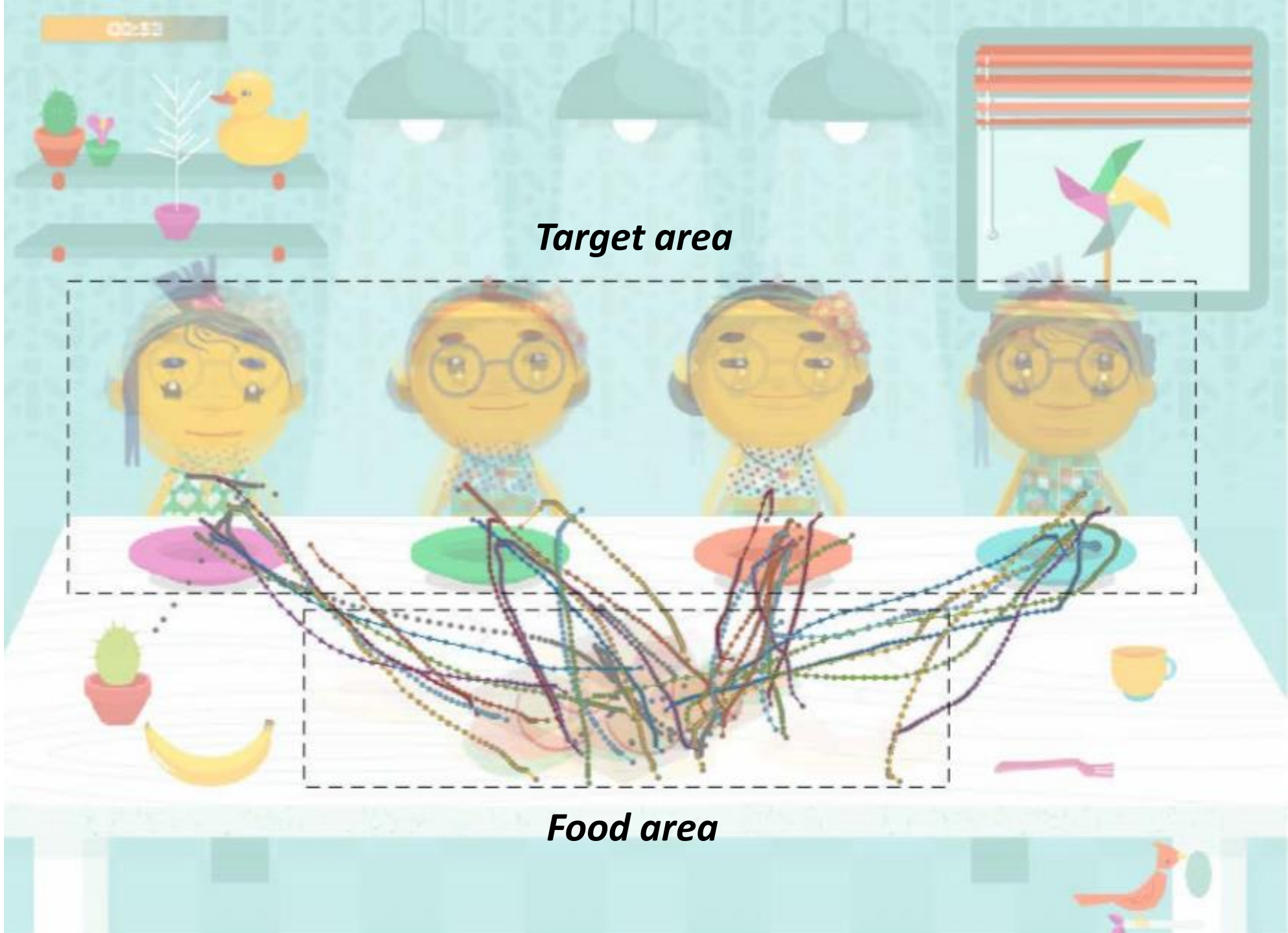
Participants:

- Typically developing (TD) and children with autism (ASD)
- Age 3-6 years old

Task:
“Sharing” game on the ipad

Inclusion criteria

- **Goal directed, point-to-point movements:** Food-target swipes shorter than 2s
- **Participants who followed task demand:** at least 10% swipes consisting of food-target swipes

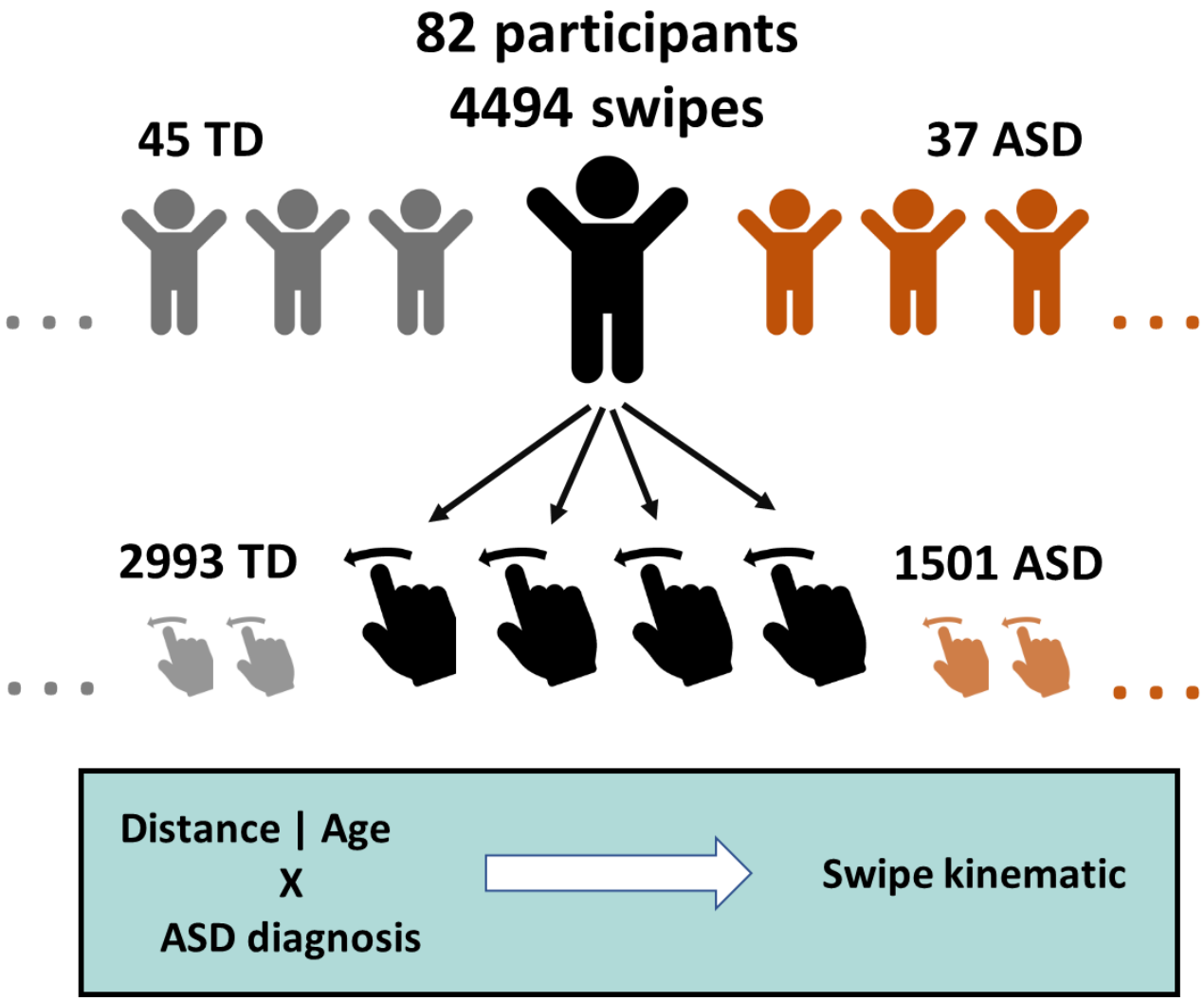


Multilevel Regression Analysis

Model accounted for "clustering" of swipes:

- **Random intercept**
  Individual differences in swipe kinematic (mean)

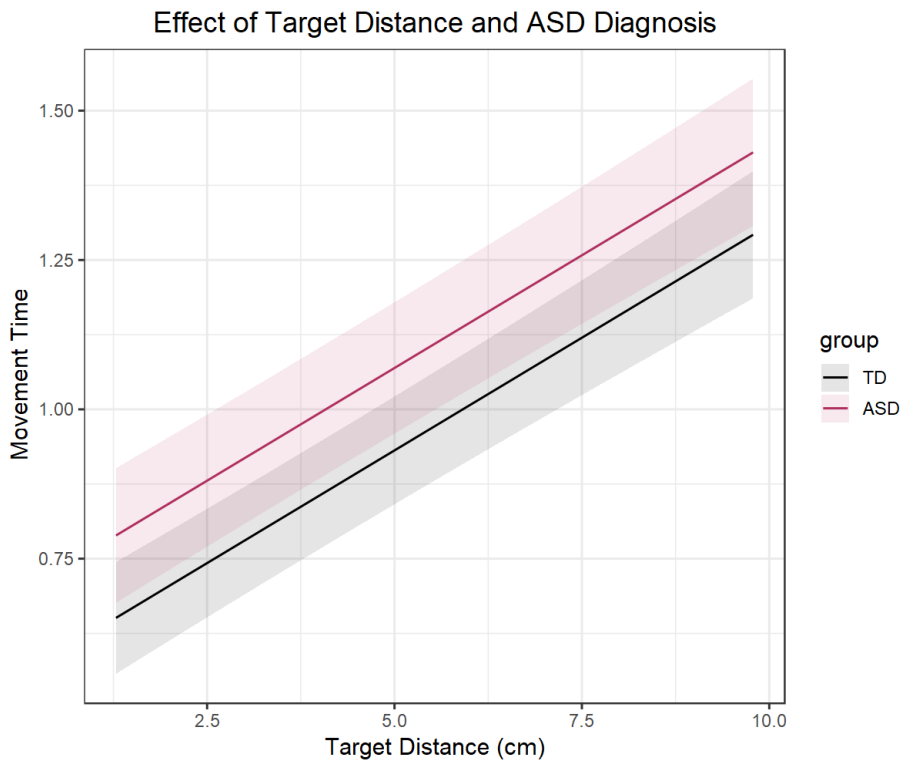
- **Random slope**
  Individual differences in the effect of distance on swipe kinematic



Results: Effect of Distance

Positive relationship with distance (p<0.001)
for all kinematic variables except % deceleration phase.

Movement Time
0.08s /cm



Peak velocity
Time to Peak velocity
14% /cm

Peak velocity (1MU)
5% /cm

Movement units
11% /cm

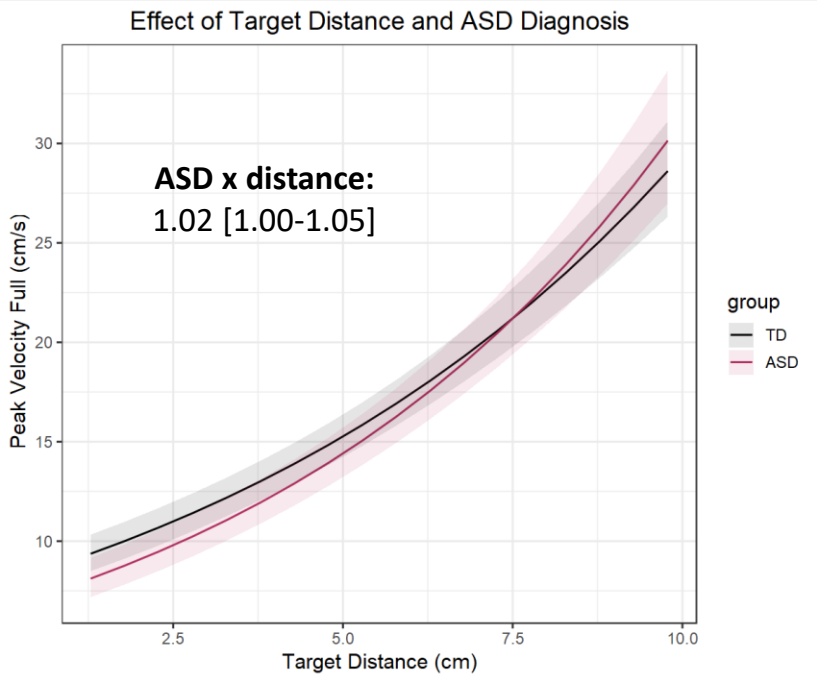
% deceleration phase
No relationship

(MacKenzie, 1987)

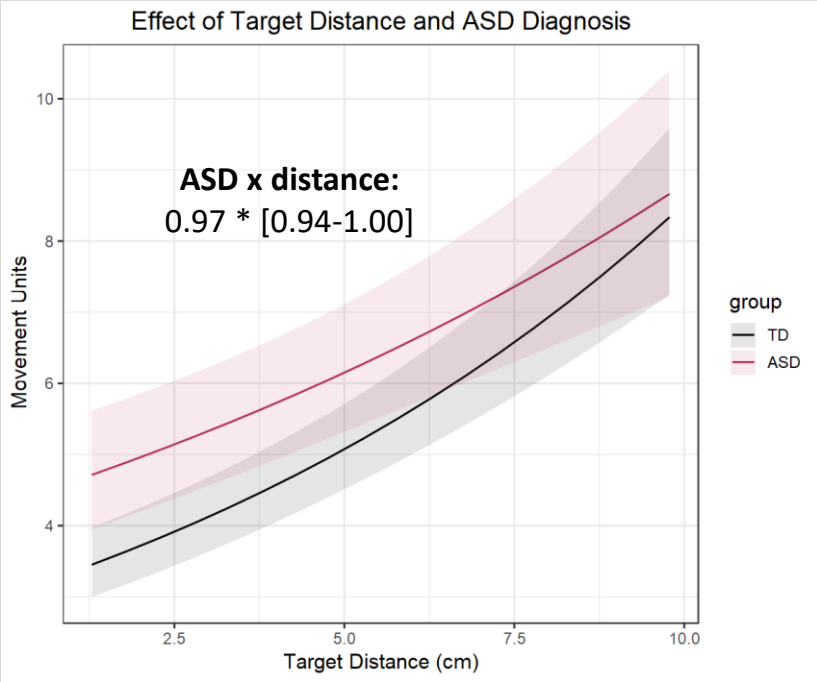
Results: Effect of ASD
ASD x Distance

ASD showed **2% larger increase in Peak Velocity** and **3% smaller increase in movement units** with every cm

Peak Velocity



Movement units

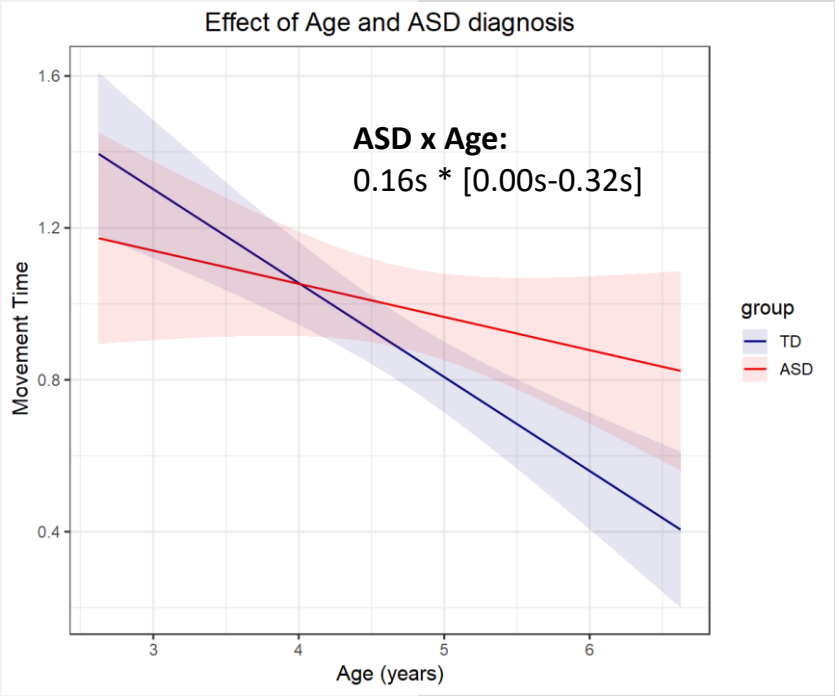


** p<0.05 ** p<0.01 *** p<0.001*

Results: Effect of ASD
ASD x Age

Movement Time

***Longer** in ASD, for older children*

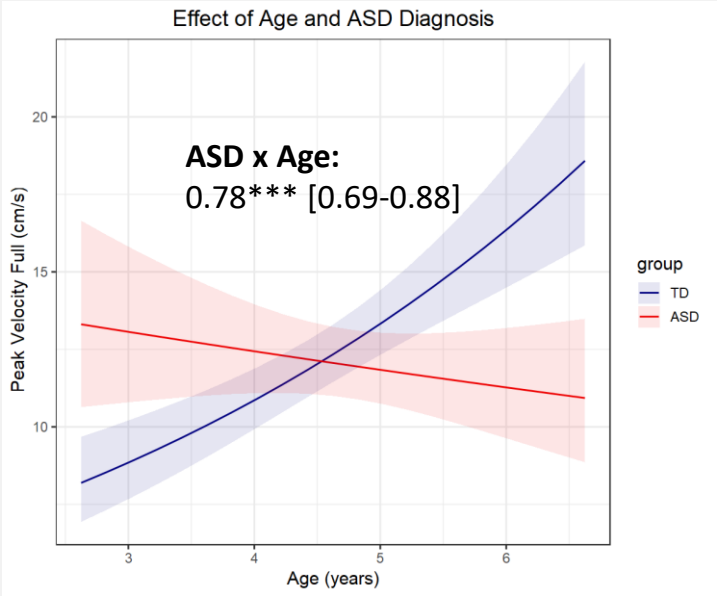


** p<0.05 ** p<0.01 *** p<0.001*

Results: Effect of ASD
Early phase: feedforward and forward model

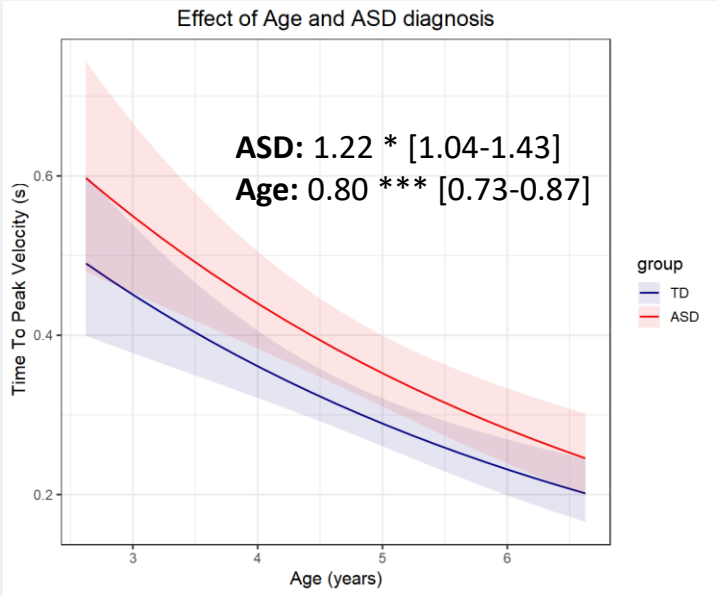
Peak Velocity

Higher in ASD *for younger children*
Lower in ASD, *for older children*



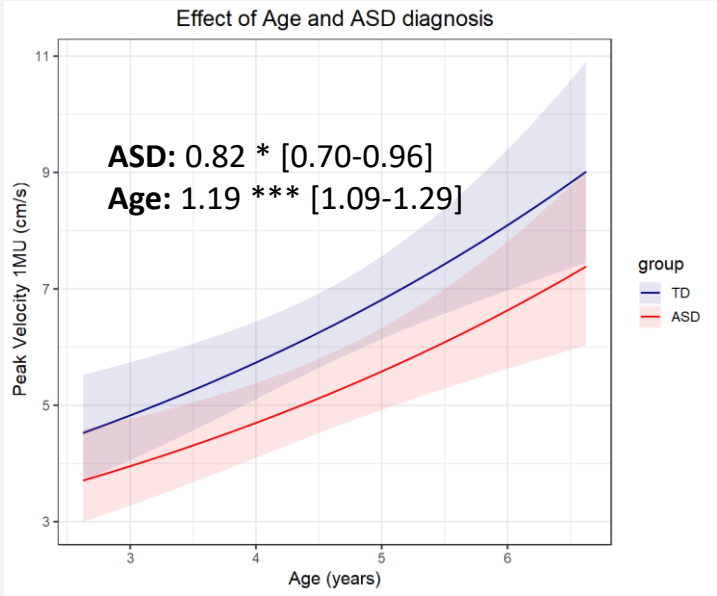
Time to Peak Velocity

22% *Longer* *in ASD*



Peak Velocity (1MU)

18% *Lower* *in ASD*

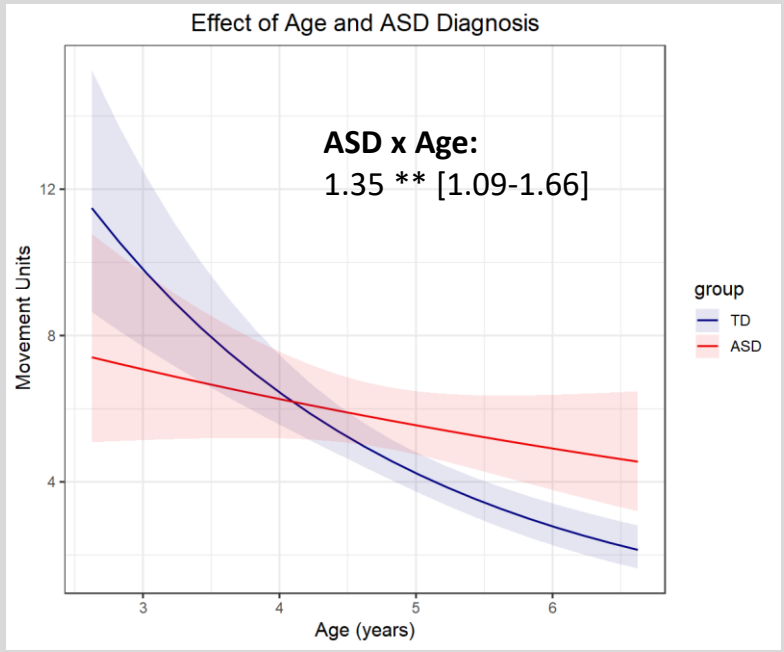


** p<0.05 ** p<0.01 *** p<0.001*

Results: Effect of ASD
Late phase, feedback

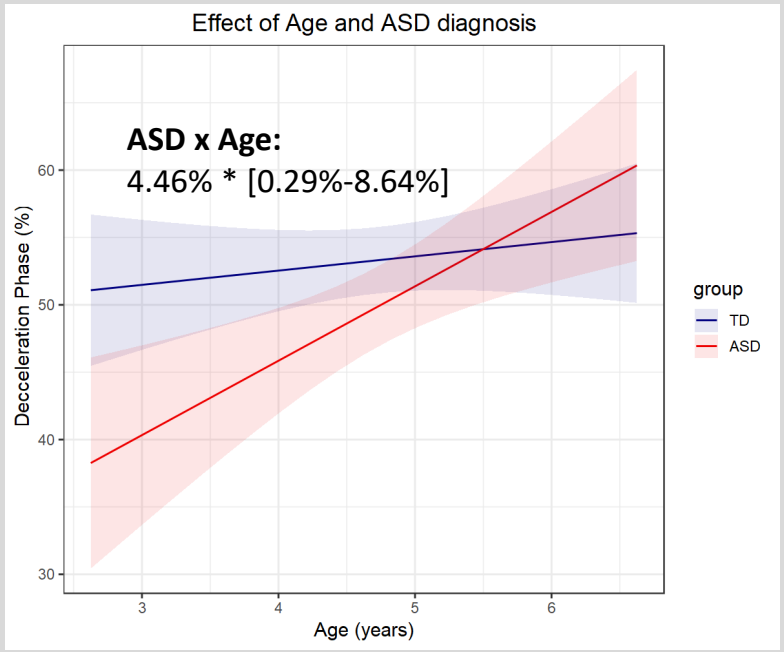
Movement units

Greater in ASD, for older children



% deceleration phase

Smaller in ASD, for younger children



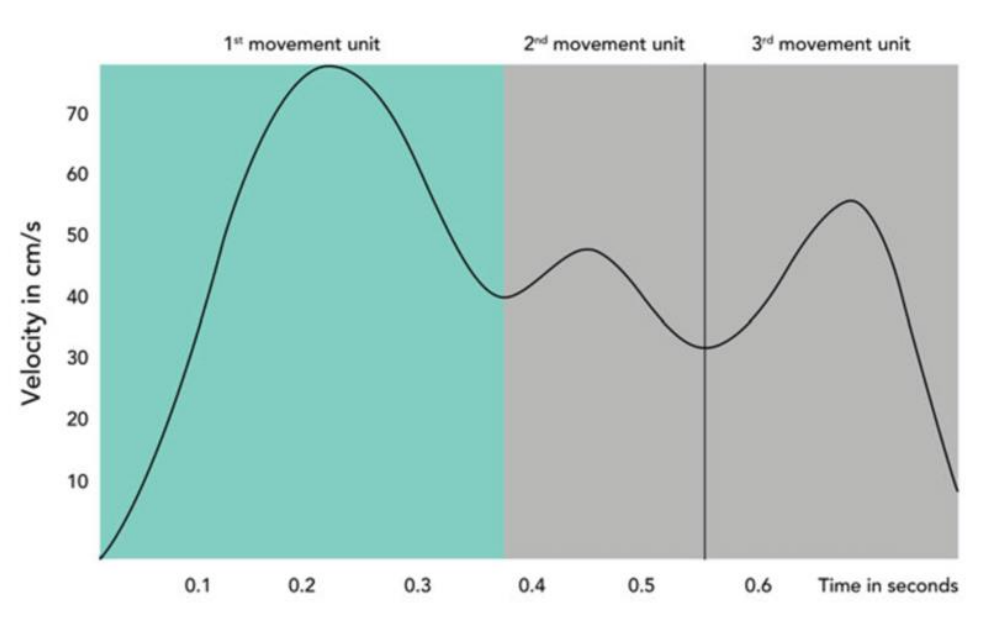
** p<0.05 ** p<0.01 *** p<0.001*

Motor kinematics are different between ASD and TD
for both early and late motor control processes

EARLY PHASE

Feedforward + Forward model

- **Peak velocity**
- **Time to peak velocity**
- **Peak velocity 1MU**



LATE PHASE

Sensory Feedback

- **Movement units**
- **% deceleration phase**

EARLY and LATE

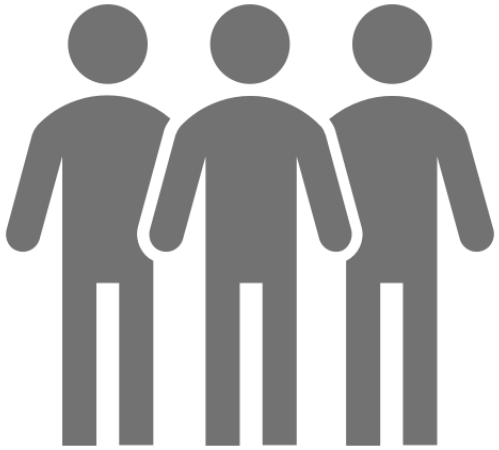
- **Movement time**

Figure from Gottwald et al. (2017)

Age is an important consideration

Children

Age 3-4 (Forti et al., 2011)
Age 4-6 (Campione et al., 2016)
Age 3-8 (Dowd et al., 2012)
Age 6-9 (Yang et al., 2014)
Age 8-12 (Mari et al., 2003)



Young adults and adults

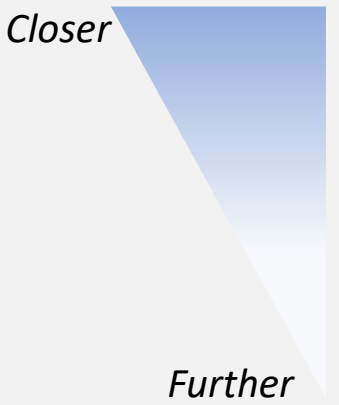
(Glazebrook et al., 2006;
Cook et al., 2013)

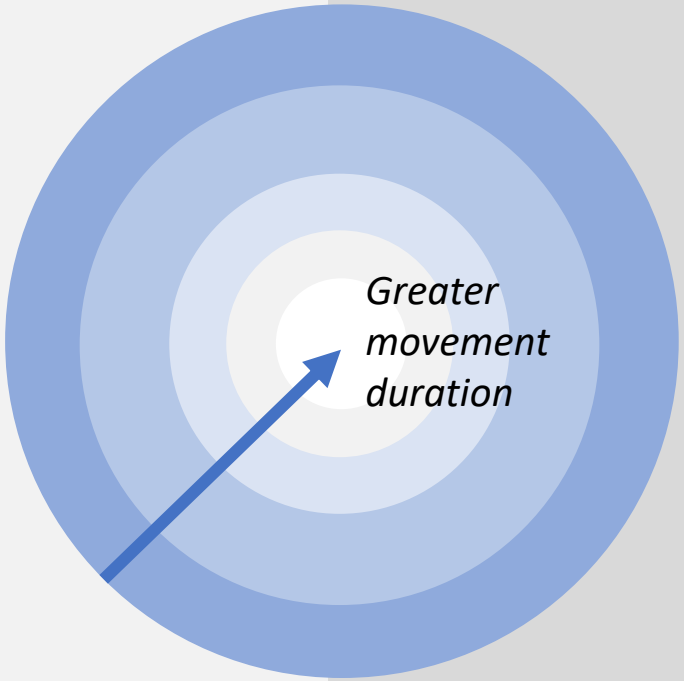
Earlier Studies

Intact feedforward control:

Children with ASD are able to specify motor commands to achieve different goal distances

Target distance





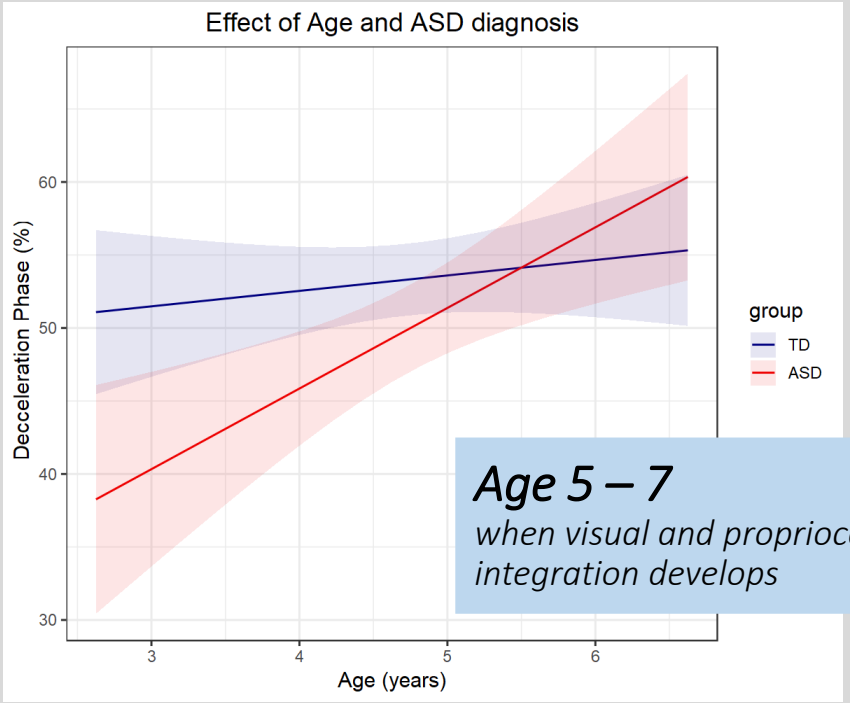
Target size

(Fitts, 1954)

Intact but later recruitment of feedback control:

No difference in % deceleration phase for older children with ASD

% deceleration phase



Age 5 – 7

when visual and proprioceptive integration develops

(von Hofsten & Rösblad 1988)

Impairment in forward models?

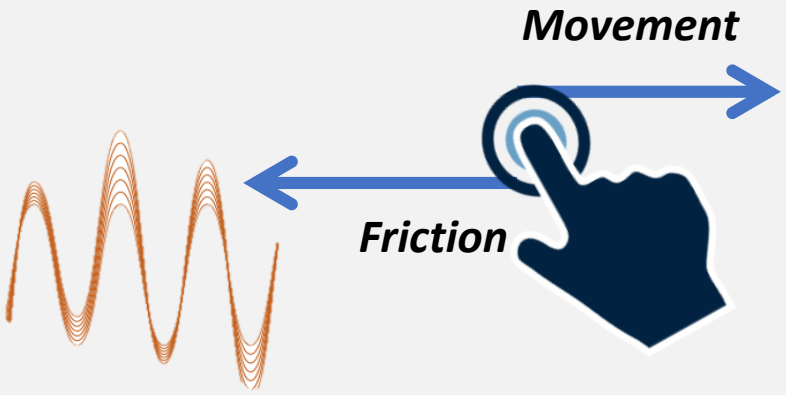
Peak Velocity 1MU is ***18% lower*** in ASD

Movement units is ***higher in ASD*** *in older children*

EARLY PHASE

Feedforward + Forward model

- *Forward model compares predicted future state with the desired state*



LATE PHASE

Sensory Feedback

- *Without an accurate forward model, delayed sensory feedback is needed*

Duration of movement

Eg. Different intentions possible, to give or to drink

Forward Model

Prospective control

Intention understanding

MOVEMENT *Prediction* COGNITION

Motor anticipation

Social cognition

Eg. Anticipating and correcting self-induced force changes

Eg. Inferring false beliefs in the Sally-Ann task

(Sinha et al., 2014)
(Fournier et al., 2010)
(Trevarthen and Delafield-butt., 2013)

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Phil Rowe

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Thank you!

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https://www.strath.ac.uk/research/innovationinautism/

HARIMATA

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Coefficients from regression models

Note: To ensure that the assumption for normality of residuals is met, Regression models were based on Log(variable) for *Peak Velocity (Full), Peak Velocity (1MU), Movement Units and Time To Peak Velocity*. Regression presented here are the exponentiated coefficients of the model output for these variables.

	Peak Velocity Full (cm/s)	**Peak Velocity 1MU (cm/s)**	**Movement Units**	**Time to Peak Velocity (s)**	**Decceleration Phase (%)**	**Movement Time (s)**
Predictors	*Estimates*	*Estimates*	*Estimates*	*Estimates*	*Estimates*	*Estimates*
Intercept	128.78 *** (119.44 – 138.85)	66.12 *** (59.75 – 73.18)	4.56 *** (4.04 – 5.15)	0.30 *** (0.27 – 0.33)	53.41 *** (50.94 – 55.87)	0.85 *** (0.76 – 0.94)
Target Distance	1.14 *** (1.12 – 1.16)	1.05 *** (1.03 – 1.07)	1.11 *** (1.09 – 1.13)	1.14 *** (1.11 – 1.16)	-0.38 (-1.15 – 0.39)	0.08 *** (0.07 – 0.09)
Age	1.23 *** (1.14 – 1.32)	1.19 *** (1.09 – 1.29)	0.66 *** (0.58 – 0.74)	0.80 *** (0.73 – 0.87)	1.06 (-1.34 – 3.46)	-0.25 *** (-0.34 – -0.15)
ASD Diagnosis	0.93 (0.82 – 1.05)	0.82 * (0.70 – 0.96)	1.24 * (1.03 – 1.50)	1.22 * (1.04 – 1.43)	-3.01 (-6.59 – 0.58)	0.13 (-0.01 – 0.27)
Distance X ASD	1.02 (1.00 – 1.05)		0.97 * (0.94 – 1.00)			
Age X ASD	0.78 *** (0.69 – 0.88)		1.35 ** (1.09 – 1.66)		4.46 * (0.29 – 8.64)	0.16 * (0.00 – 0.32)
Random Effects						
σ^2	0.10	0.35	0.23	0.35	397.62	0.06
τ_{00}	0.06 Subject.f	0.11 Subject.f	0.16 Subject.f	0.10 Subject.f	67.47 Subject.f	0.08 Subject.f
τ_{11}	0.00 Subject.f.Displacement.c	0.00 Subject.Displacement.c	0.00 Subject.f.Displacement.c	0.00 Subject.f.Displacement.c	7.20 Subject.f.Displacement.c	0.00 Subject.f.Displacement.c
ρ_{01}	-0.59 Subject.f	0.52 Subject.f	-0.39 Subject.f	-0.02 Subject.f	-0.66 Subject.f	-0.04 Subject.f
Observations	4494	4480	4480	4493	4494	4494

** p<0.05 ** p<0.01 *** p<0.001*