Children's interaction with touchscreen devices: Performance and validity of Fitts' law

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Children's interaction with touchscreen devices: Performance and validity of Fitts' law

Savita Yadav[1] | Pinaki Chakraborty[1] | Lokesh Meena[1] | Deepanshu Yadav[1] | Prabhat Mittal[2]

[1]Department of Computer Science and Engineering, Netaji Subhas University of Technology, New Delhi, India
[2]Department of Commerce, Satyawati College (Evening), University of Delhi, Delhi, India

Correspondence
Savita Yadav, Department of Computer Science and Engineering, Netaji Subhas University of Technology, New Delhi 110078, India.
Email: savitaydv@yahoo.com

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Abstract

Interaction of human beings with various types of apparatus, including many digital gadgets, follows Fitts' law. The objectives of this study were to assess the ability of children to acquire onscreen targets while using smartphones and determine if their interaction with smartphones follows Fitts' law. We developed an app implementing the standard two-dimensional target selection task and provided it to 30 children aged between 4 and 10 years. We observed them to use the app and acquire onscreen targets using the tap gesture and the drag and drop gesture. We noted the index of difficulty (ID), movement time (MT), and throughput (TP) for the movement tasks. MT decreased and TP increased with the age of the children ($p < .05$). MT was significantly ($p < .05$) higher for the drag and drop gesture than for the tap gesture for 4 to 6-year-old children but not for 7 to 10-year-old children. No strong correlation ($-.142 \le r \le .292$) was observed between ID and MT for the children aged between 4 and 10 years indicating that the interaction of children in this age range with smartphones does not obey Fitts' law. We recommend that smartphone apps for children be developed taking into consideration their ability to acquire onscreen targets.

KEYWORDS
children, Fitts' law, movement task, smartphone, touchscreen

1 | INTRODUCTION

> *"A 2-year-old traces letters with her finger on a tablet touchscreen. A 4-year-old watches videos on YouTube. A 6-year-old asks a voice-controlled digital assistant whether eagles eat snakes."*—Danovitch (2019)

Children are now exposed to smartphones and other touchscreen devices at an early age (Kabali et al., 2015). They are fond of playing with smartphones because of their small size, attractive design, and multimedia features. Children use a wide variety of apps as they grow up (Yadav & Chakraborty, 2018) and suitably designed apps can contribute in child development (Griffith et al., 2020). Like other users, children interact with smartphones by making gestures with their fingers on the screen. Children learn to perform various touchscreen gestures between 4 and 8 years of age (Yadav et al., 2020). However, fingers obfuscate a part of the screen and lack the precision of a stylus or a computer mouse. Moreover, children are known to have inferior fine motor skills than adults (Leversen et al., 2012). A proper understanding of the ability of children to acquire targets on a touchscreen using their fingers can help in designing more appropriate apps for them (Yadav & Chakraborty, 2021).

In 1954, Paul M. Fitts proposed a law to predict the time required by a person to move a hand and fingers and acquire targets when using a gadget (Fitts, 1954). He drew a similarity between movement of human beings and transmission of information. Fitts' law predicted the movement time (MT) required by a person to acquire a target with width W at a distance D (Figure 1) as follows:

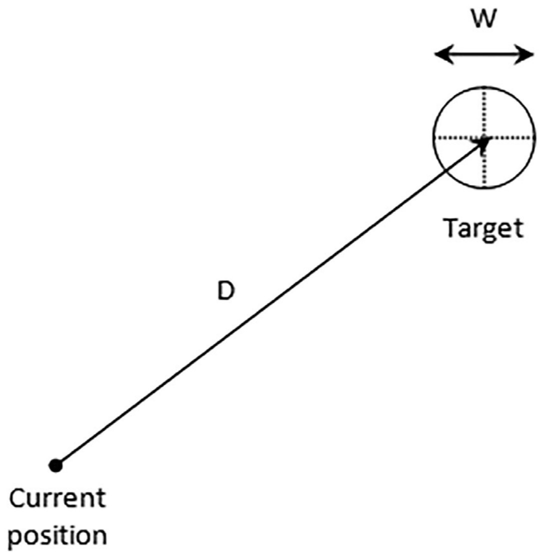

FIGURE 1 Schematic diagram of Fitts' law being used to predict the time required to acquire a target of width *W* at a distance *D*

$$\mathrm{MT} = a + b\log_2(2D/W). \quad (1)$$

Here, *a* and *b* are constants whose values have to be empirically determined for different gadgets. The index of difficulty (ID) of a movement task is defined in terms of *W* and *D* and measured in bits.

$$\mathrm{ID} = \log_2(2D/W). \quad (2)$$

Fitts's law may also be represented as follows:

$$\mathrm{MT} = a + b\,\mathrm{ID}. \quad (3)$$

The throughput (TP) of a gadget is defined as the ratio of ID and MT and measured in bits/s.

$$\mathrm{TP} = \mathrm{ID}/\mathrm{MT}. \quad (4)$$

Fitts' law has been used to model the interaction of users of different categories with different types of gadgets. For example, Fitts' law has been used to study the interaction of motion-impaired users (Hwang et al., 2005) and visually impaired users (El Lahib et al., 2018) with computers. Again, Fitts' law has been used to study the usability of interfaces controlled by gaze (Hansen et al., 2018) and gesture (Pomboza-Junez et al., 2019). The discipline of human–computer interaction explores how effective and convenient interactions with digital devices can be designed for people with different skill sets. Fitts' law provides a useful mechanism for experimentally testing the performance of human beings when subjected to pointing tasks using various input devices. This knowledge can assist software developers in selecting the size of icons and the distance between them so that users with diverse backgrounds can use the software at an acceptable pace.

Fitts' law-based studies have been conducted on children as well. Children have unique requirements and the manner in which they interact with digital devices is different from that of adults. Children use computers and smartphones on a daily basis to pursue academic and recreational activities. Studies on how children acquire onscreen targets while using computers and smartphones can help in optimizing performance and positively enhancing the experience of children. In an early study, Wallace et al. (1978) constructed a mechanical apparatus and observed 4-year-old children interacting with it. They found that the interaction of the children with the apparatus obeyed Fitts' law. The proliferation of digital technologies in the last three decades led to the use of Fitts's law to model the interaction of human beings with different types of devices like computer mouse, joystick, touchpad, and stylus (Soukoreff & MacKenzie, 2004). Some researchers have focused on the interaction of children with different types of computer input devices. For example, Hourcade et al. (2004) found that the interaction of 4 and 5-year-old children with a computer mouse follows Fitts' law and Vatavu et al. (2015) found that the ability of children to interact with touchscreen devices improves significantly between 3 and 6 years of age. The objectives of this study were to determine if the interaction of children with a touchscreen obeys Fitts' law and to understand the effects of age and touchscreen gesture on the time taken by children to acquire onscreen targets.

2 | LITERATURE REVIEW

2.1 | Fitts' law-based studies

Smartphones, tablet computers, and many other devices used today have touchscreens. These devices allow users to manipulate onscreen icons and menus with the touch of a finger (Le et al., 2018). Such a direct manipulation style facilitated by touchscreens enables people with different levels of expertise to use computing systems (Cáliz et al., 2021). However, a finger lacks the precision with which a stylus or a mouse can perform a pointing task and often misses the target on the screen (Ahsanullah et al., 2014). In the recent years, some researchers have studied the validity of Fitts' law to the interaction with touchscreens. For example, MacKenzie (2015) investigated the impact of position of the device and the type of task on TP. It was found that the TP for one-dimensional tasks was 15% higher than that for two-dimensional tasks. TP was however not affected by whether the device was stationary or moving. Borish et al. (2020) conducted an experiment in which it was found that MT is affected by the distance to the target but not by the size of the target. Additionally, users required more than the expected time to acquire targets located too close to the current location. Other contemporary studies have found that the size of the touchscreen affects the speed and accuracy with which touchscreen gestures are performed (List & Kipp, 2019) and it is easier to perform various touchscreen gestures on screens that are 6 inches or more in size (Tsai et al., 2017).

Children have a limited understanding of digital technologies and less developed fine motor skills as compared to adults, and these factors affect how they interact with touchscreen devices (Anthony et al., 2012). Interacting with touchscreen devices requires acquiring onscreen targets of different sizes and at different distances, and hence it is important to know if Fitts' law is applicable for children's interaction with touchscreen devices. Few researchers have experimented with the validity of Fitts' law to the interaction of children with touchscreen devices. For example, Vatavu et al. (2015) conducted an experiment with 3 to 6-year-old children and found that the older children could tap 2.5 times faster and drag 1.3 times faster than the younger ones. In addition, the older children could touch targets close to the center of the screen with ease as compared to the younger children. Vatavu et al. (2015) remarked imposing a limit on the maximum distance of the dragging path would lead to a superior performance by children aged 3–6 years. In another study, Cassidy et al. (2019) observed that for children aged 8 and 9 years the MT for drag and drop gesture does not vary significantly for finger- and stylus-based interactions. However, adequate research to establish the validity of Fitts' law for children of different age groups interacting with touchscreen devices has not been conducted.

> **RQ1.** Does the interaction between children and a touchscreen obey Fitts' law, that is, is there a linear relationship between ID and MT?

2.2 | Touchscreen gesture-related studies

The intuitive environment provided by touchscreen devices is suitable for using educational software for children (Nácher Soler, 2020). However, a thorough knowledge of how children use these touchscreen devices (Nácher Soler, 2020) and their ability to perform various touchscreen gestures (Nacher et al., 2015) is essential for designing effective interactions. The motor skills of children are still developing and they often encounter problems with interactions demanding compound gestures (Woodward et al., 2017). Researchers like Aziz (2013) and Nacher et al. (2015) have conducted experiments in the last decade to understand the capability of children aged between 2 and 12 years to perform various touchscreen gestures. As children grow up, they gradually acquire skill to perform complex gestures on a touchscreen (Yadav et al., 2020). Children aged 4 years are able to tap at an intended place on a touchscreen. They first master simple single-finger gestures like tap and slide, and become able to perform more complex gestures like drag and drop by 7 years of age (Yadav et al., 2020). Chang et al. (2014) conducted an experiment in which it was observed that 11 to 14-year-old children were slower than young adults in acquiring onscreen targets and the children found it difficult to drag objects on a small touchscreen. Alternatively, a study with children aged 3–6 years showed that they find it difficult to drag objects over a long distance across a touchscreen (Vatavu et al., 2015). The position of the targets on the screen also affects the performance of children. For example, Woodward et al. (2016) observed that children tend to miss small targets placed near the edges of the screen and also sometimes touch them accidentally. However, none of the previous studies covered a wide age range of children and investigated how the ability of children to acquire onscreen targets varies with age and touchscreen gesture being used.

> **RQ2.** Does the ability to acquire onscreen targets improve with age of children and differ with touchscreen gesture being used?

Figure 2 shows our research model.

3 | METHODOLOGY

3.1 | The apps

We developed a smartphone app[1] to test Fitts' Law (see Equation (1)). The app implemented the standard two-dimensional target selection task (ISO, 2012). The app displayed 13 circular targets arranged uniformly in a circle covering the width of the screen of a smartphone (Figure 3). The app had six sequences of targets, namely Sequences I through VI, with different combinations of *D* and *W* and thus having different values of ID. A user had to acquire the targets in a fixed order to complete a trial. The app allowed acquiring the targets using the tap gesture (Figure 3a) and the drag and drop gesture (Figure 3b). The app recorded the gestures made by a user on the screen and calculated the values of ID, MT, and TP according to Equations (2)–(4) at the end of a trial.

3.2 | Study protocol

We performed an experiment with children of three age groups, namely 4–6 years, 7 and 8 years, and 9 and 10 years. Each age group was represented in the study by 10 children. The inclusion criterion was that the children should have used smartphones or other touchscreen devices earlier. We provided a smartphone having a 7.2 cm $\times$ 12.7 cm screen with our app running on it to the children. We explained the children how to use the app and let them practice using it for 5 min. We then asked the children to acquire the targets in Sequences I through VI using the tap gesture (Video S1) and the drag and drop gesture (Video S2). We allowed the children to hold the phone in any way according to their convenience but use only a single finger of their choice to complete a trial. We asked the children to complete the trials in minimum time and with minimum errors. We noted the values of MT and TP for each trial (Appendix S1).

3.3 | Data analysis

The difference in MT between the tap gesture and the drag and drop gesture was analyzed using Student's *t*-test for all age groups and sequences. The correlation between ID and average MT was calculated for both touchscreen gestures and for all age groups and

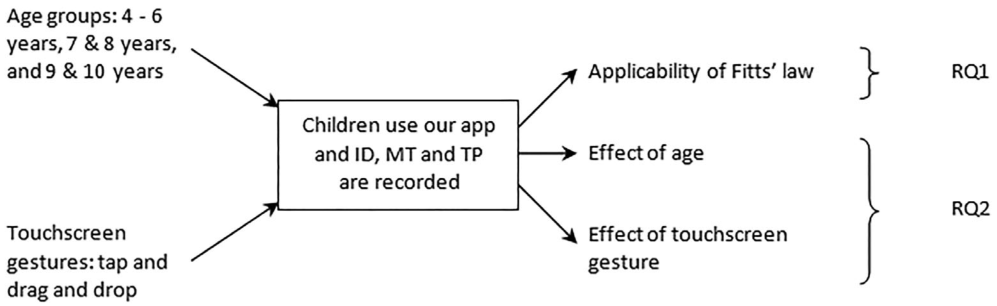

FIGURE 2 Research model. ID, index of difficulty; MT, movement time; TP, throughput

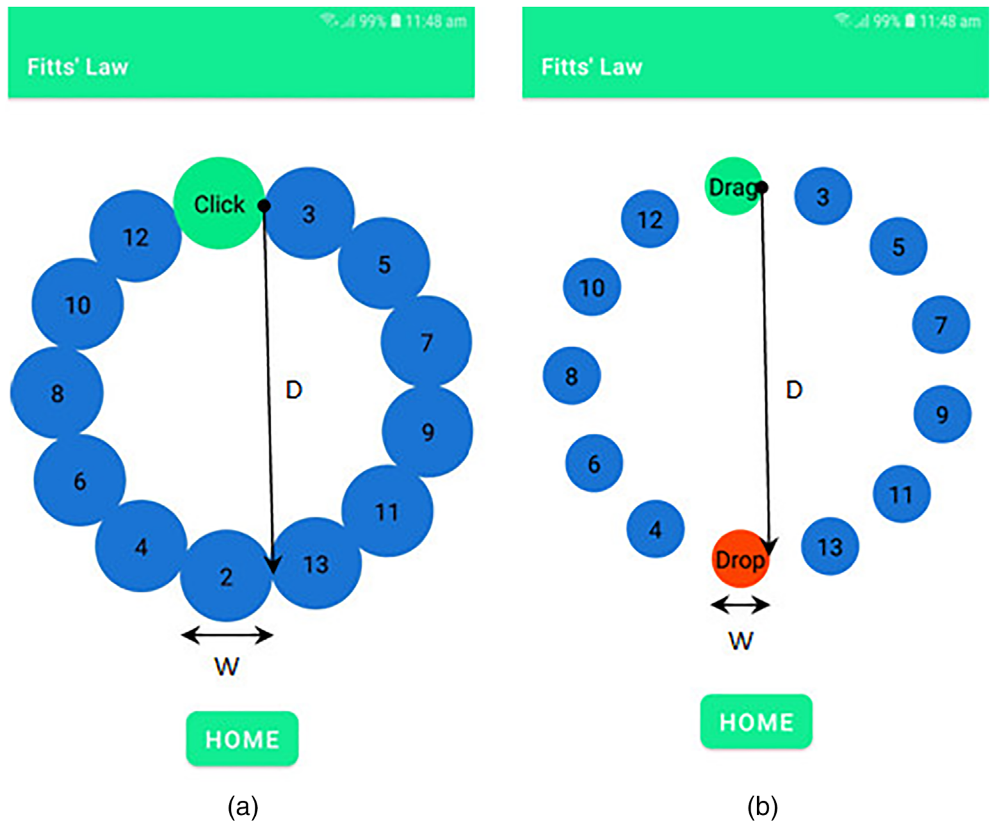

FIGURE 3 Measuring movement time and throughput using our app for (a) tap gesture in Sequence I and (b) drag and drop gesture in Sequence VI

sequences. Further, the effects of age and touchscreen gesture were analyzed using inferential statistics. Data of all sequences were checked for normality using Kolmogorov–Smirnov test (Massey Jr, 1951) and appropriate statistical inference tests were applied. ANOVA-one factor test and Kruskal–Wallis test (Kruskal & Wallis, 1952) were used to analyze the difference in MT across age groups. Similarly, Mann–Whitney *U* test (Mann & Whitney, 1947) and Student's *t*-test were used to analyze the difference in MT for different touchscreen gestures. The statistical tests were conducted using SPSS Statistics 27 (IBM Corp, Armonk, NY).

4 | RESULTS

Table 1 shows average MT and average TP of the children of the three age groups for the two touchscreen gestures and the six sequences. The children took up to 839.21 ms when using the tap gesture and up to 1854.05 ms when using the drag and drop gesture to acquire targets up to 5.40 cm away on the screen. A statistically significant but weak correlation ($r = .292$, $p < .05$) between ID and average MT was found for 7 and 8-year-old children for the tap gesture. However, no statistically significant correlation between ID and average MT was observed for the same children for the drag and drop gesture. For the children of the other two age groups, no statistically significant correlation between ID and average MT was observed for either touchscreen gesture. This answered RQ1.

Table 2 shows an analysis of the difference between average MT across age groups. The test statistic was found to be significant for all the six sequences at $p < .05$ level. This indicated that the ability of children to acquire onscreen targets improves with age. Similarly, Table 3 shows an analysis of the difference between average MT for different touchscreen gestures. The test statistic was found to be significant for Sequences I, II, and V at $p < .05$ level and Sequences III and VI at $p < .1$ level, while the test statistic was insignificant for

TABLE 1 Average movement time and average throughput of children of different age groups

Age group (years)	Sequence	D (cm)	W (cm)	ID (bits)	Tap gesture Average MT (ms)	Average TP (bits/s)	r	p-value	Drag and drop gesture Average MT (ms)	Average TP (bits/s)	r	p-value
4–6	I	5.40	1.30	3.0544	812.42	2.9994	−.142	.283	1854.05	1.6010	−.037	.779
	II	5.40	1.06	3.3489	713.07	4.1874			1626.90	1.9129		
	III	5.40	0.82	3.7193	773.61	5.5971			1386.02	1.7663		
	IV	4.40	1.06	3.0534	789.23	4.3929			1210.99	2.3076		
	V	4.40	0.82	3.4238	783.28	4.9193			1165.90	3.1678		
	VI	3.40	0.82	3.0518	839.21	3.0985			1112.59	3.0664		
7 and 8	I	5.40	1.30	3.0544	513.50	3.8161	.292	.024**	662.45	3.7285	.086	.512
	II	5.40	1.06	3.3489	623.43	4.8109			614.72	3.9923		
	III	5.40	0.82	3.7193	620.31	3.7440			637.30	4.3530		
	IV	4.40	1.06	3.0534	493.47	5.0295			512.68	4.6560		
	V	4.40	0.82	3.4238	631.35	5.0158			581.64	4.8565		
	VI	3.40	0.82	3.0518	556.06	4.3860			597.33	3.7996		
9 and 10	I	5.40	1.30	3.0544	515.02	4.1542	.081	.539	652.54	3.1803	−.072	.585
	II	5.40	1.06	3.3489	449.75	5.4527			545.59	3.6332		
	III	5.40	0.82	3.7193	509.23	5.8556			502.35	5.1964		
	IV	4.40	1.06	3.0534	415.39	5.0131			482.00	4.5454		
	V	4.40	0.82	3.4238	443.03	5.4847			559.40	4.3207		
	VI	3.40	0.82	3.0518	485.92	5.6864			538.29	4.2269		

Abbreviations: ID, index of difficulty; MT, movement time; TP, throughput.
**$p < .05$.

TABLE 2 Analysis of the difference between the averages of movement time across age groups

Sequence	Average MT (ms) 4–6 years	7 and 8 years	9 and 10 years	Test statistic	p-value	Statistical test
I	1333.24 ± 131.42	587.97 ± 44.15	583.78 ± 43.41	28.932	.000**	Kruskal–Wallis
II	1169.99 ± 107.53	619.08 ± 44.16	497.67 ± 41.12	27.022	.001**	Kruskal–Wallis
III	1079.81 ± 86.36	628.80 ± 30.10	505.79 ± 38.16	27.904	.000**	ANOVA
IV	1000.11 ± 56.62	503.07 ± 21.38	448.70 ± 39.51	53.028	.000**	ANOVA
V	974.59 ± 51.57	606.50 ± 32.32	501.22 ± 40.74	34.554	.000**	ANOVA
VI	975.90 ± 45.69	576.69 ± 35.36	512.10 ± 37.16	40.114	.000**	ANOVA

Abbreviation: MT, movement time.
**$p < .05$.

Sequence IV. This indicated that the ability of children to acquire onscreen targets depends on the touchscreen gesture they are using for most values of ID.

The effects of age and touchscreen gesture on MT were analyzed for all six sequences (Figure 4), and three salient trends were observed. First, the children typically required lesser MT when using the tap gesture than when using the drag and drop gesture. However, there were a few exceptions. For example, the 7 and 8-year-old children required more MT for the tap gesture than for the drag and drop gesture for Sequence V. Second, a decrease in MT was observed with an increase in age of the children for both the touchscreen gestures and for all the six sequences. In other words, the average MT of 4 to 6-year-old children was higher than that of 7 and 8-year-old children which was in turn higher than that of 9 and 10-year-old children for all touchscreen gestures and sequences. Third, the decrease in MT was the sharpest between the 4–6 years age group and the 7 and 8 years age group for the drag and drop gesture. The children aged 4–6 years, 7 and 8 years, and 9 and 10 years required up to 128.21%, 29.01%, and 26.70% more MT for the drag and drop gesture compared to the tap gesture ($p < .05$), respectively. This answered RQ2.

TABLE 3 Analysis of the difference between the averages of movement time for different touchscreen gestures

Sequence	Average MT (ms)		Test statistic	*p*-value	Statistical test
	Tap gesture	Drag and drop gesture			
I	613.65 ± 32.09	1056.35 ± 115.63	278.500	.011**	Mann–Whitney *U*
II	595.42 ± 31.58	929.07 ± 98.11	303.000	.030**	Mann–Whitney *U*
III	634.38 ± 31.50	841.89 ± 82.18	327.000	.069*	Mann–Whitney *U*
IV	566.03 ± 35.72	735.22 ± 68.98	346.500	.126	Mann–Whitney *U*
V	619.22 ± 36.00	768.98 ± 59.16	2.162	.035**	Student's *t*-test
VI	627.06 ± 37.63	749.40 ± 57.35	1.784	.080*	Student's *t*-test

Abbreviation: MT, movement time.
*$p < .1$;
**$p < .05$.

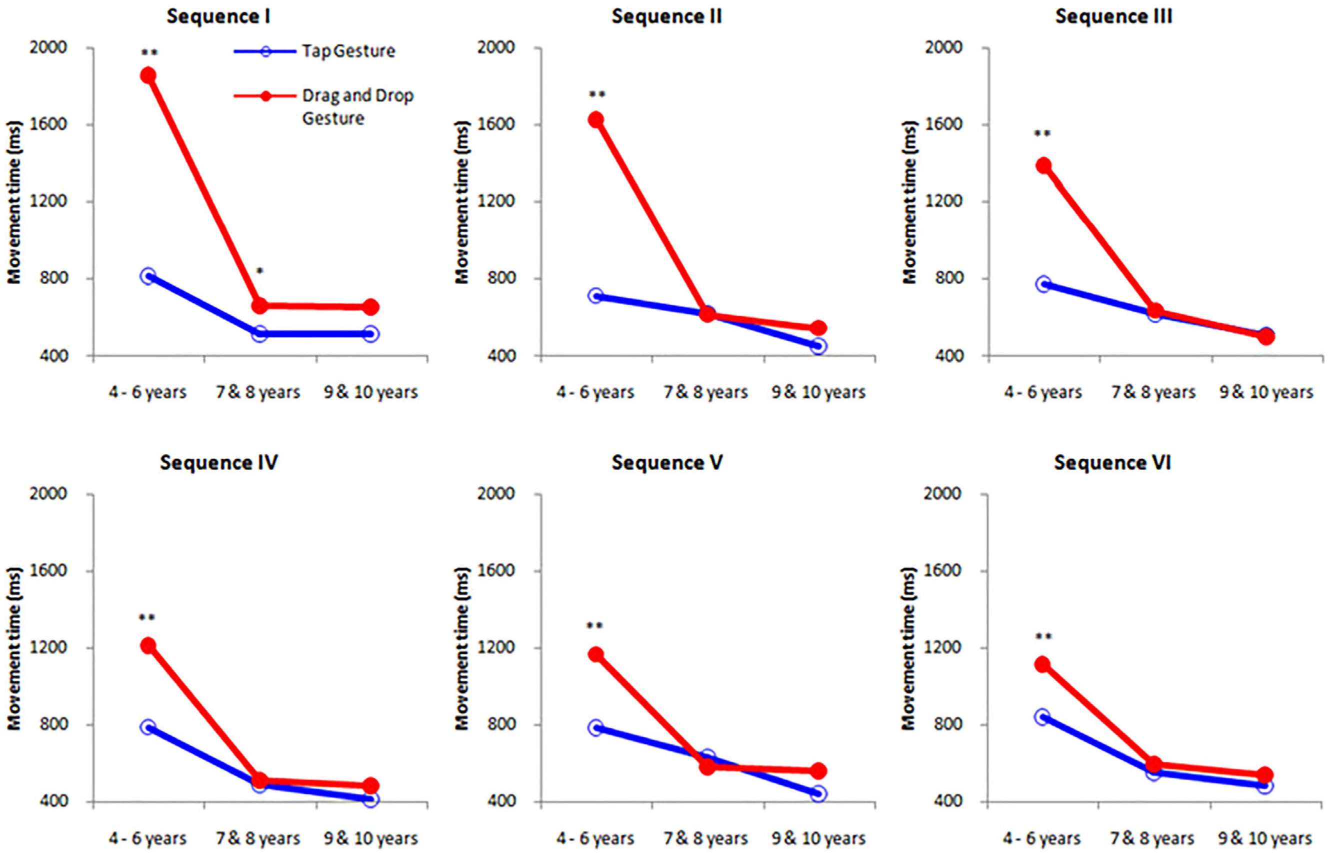

FIGURE 4 Effects of age and touchscreen gesture on movement time. *$p < .1$, **$p < .05$

5 | DISCUSSION

A linear relationship was expected between ID and MT according to Fitts' law (see Equation (3)). However, we did not find any statistically significant and strong correlation between ID and MT for children aged between 4 and 10 years when they used a touchscreen device with tap and drag and drop gestures. On the basis of these results, we infer that 4 to 10-year old children's interaction with touchscreen does not obey Fitts' law. This implies that Fitts' law is not a suitable model to design the interaction while developing smartphone apps for children and alternative models may be explored.

Earlier studies have found that children's interaction with a physical apparatus (Wallace et al., 1978) and a computer mouse (Hourcade et al., 2004) follows Fitts' law. Some researchers, like Chang et al. (2014), have studied how children older than 10 years interact with touchscreen devices and found that their interaction follows Fitts' law. However, to the best of our knowledge, there has been only one study on finger-based interaction of young children with touchscreen devices. Woodward et al. (2020) have recently studied the interaction of 5 to 10-year-old children with smartphones and found that the interaction of the children followed Fitts' law. Our findings contradict those of Woodward et al. (2020). The sample size in the current study and the study by Woodward et al. (2020) was 30 and 54, respectively. A limitation of these studies was their small sample size. We, therefore, call for more intensive research on young children's interaction with touchscreen devices with larger sample sizes.

There may be two possible explanations for the violation of Fitts' law as observed in this study. First, the small size of the screen of a smartphone means that children have to acquire targets only a few centimeters away from the current position. Second, the interaction with a touchscreen is inherently different from the interaction with other input devices like a mouse or a touchpad. A user needs to touch the screen to acquire targets when using a touchscreen device while the user requires manipulating a mouse or a touchpad to see intended effects on the screen. The gulf of execution is minimal in case of a touchscreen device and young children benefit from it more than other users.

The time required by children to acquire onscreen targets decreases as they grow up. For example, 4 to 6-year-old children take 812.42 ms to acquire targets that are 1.3 cm wide and 5.4 cm away while using the tap gesture, but 9 and 10-year-old children require 515.02 ms for the same. Similar observations were earlier made by Chang et al. (2014). The improvement in TP is significant between 4 and 10 years of age. The children of this age range typically require more time to acquire targets using the drag and drop gesture than when using the tap gesture. For example, 4 to 6-year-old children require 773.61 and 1386.02 ms for acquiring targets that are 0.82 cm wide and 5.4 cm away while using the tap gesture and drag and drop gesture, respectively. Yadav et al. (2020) have reported that only 10% children aged 4–6 years and only 30% children aged 7 and 8 years can perform the drag and drop gesture properly. In this study, we found that MT for the tap gesture and the drag and drop gesture differ significantly for the 4–6 years age group. The difference in MT for the two touchscreen gestures is less prominent for the older children and children aged 7 years and more are equally comfortable in acquiring onscreen targets using the tap gesture and the drag and drop gesture.

This study established that the ability of children to acquire onscreen targets improves with age and varies with touchscreen gesture. The interaction of children with the touchscreen of smartphones violates Fitts' law. These results are useful from the perspective of designing the user interface of apps for children.

6 | CONCLUSION

There are three real-life implications of this study as follows. First, some researchers have earlier found that the interaction of children with various gadgets follows Fitts' law (Hourcade et al., 2004; Wallace et al., 1978). On the contrary, we did not find any strong and statistically significant correlation between ID and MT ($-.142 \le r \le .292$). This implies that the interaction of 4 to 10-year-old children with smartphones does not obey the law (vide RQ1). Second, a large number of smartphone apps are now developed every year for entertaining (Kabali et al., 2015; Yadav & Chakraborty, 2018) and educating children (Griffith et al., 2020; Yadav & Chakraborty, 2018). Such apps should take into consideration the ability to acquire onscreen targets of the children in the target age group (vide RQ2). For example, 4 to 6-year-old children require almost twice the time when acquiring onscreen targets using the drag and drop gesture when compared to the tap gesture. Hence, apps for children in this age group should not require dragging icons across the screen. Third, apps meant for use by child–parent dyads (Ewin et al., 2021) should be developed according to the abilities of the children and not according to those of the parents. We believe that a judicious use of suitably designed apps can contribute to child development.

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ENDNOTE

[1] https://bit.ly/fitts-law-apk

PEER REVIEW

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DATA AVAILABILITY STATEMENT

The dataset has been provided as online supplementary material.

ORCID

Savita Yadav https://orcid.org/0000-0002-4334-1767
Pinaki Chakraborty https://orcid.org/0000-0002-2010-8022
Prabhat Mittal https://orcid.org/0000-0001-5352-7955

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AUTHOR BIOGRAPHIES

Savita Yadav is an assistant professor of computer science and engineering at the Netaji Subhas University of Technology, New Delhi. She received her BSc and MSc in physics from the University of Delhi, and her MTech in computer science and engineering from Guru Jambheshwar University of Science and Technology. She teaches courses and researches on human–computer interaction. The emphasis of her research is on the interaction of people with smartphones and other touchscreen devices.

Pinaki Chakraborty is an assistant professor at the Department of Computer Science and Engineering, Netaji Subhas University of Technology, New Delhi. He received his BTech from Indraprastha University, and his MTech and PhD from Jawaharlal Nehru University. He has published more than 100 research papers in journals and conference of repute. His area of research includes systems software and educational and societal use of software.

Lokesh Meena is pursuing a degree in computer engineering. His area of interest includes mobile app development, multimedia, and user experience designing.

Deepanshu Yadav is studying for his degree in computer engineering. He is interested in human–computer interaction and mobile app development with an emphasis on portability.

Prabhat Mittal is an associate professor at Satyawati College (Evening), University of Delhi. He holds a doctorate degree from the Faculty of Management Studies, University of Delhi. He has published many research articles in the fields of supply chain management, quantitative finance, and big data analytics. He was a postdoctoral fellow at the Department of Industrial and Systems Engineering, University of Minnesota. He has been an associate fellow of the Indian Institute of Advanced Studies, Shimla. His current research interests include big data, public administration, healthcare supply chain, econometric modeling, and high-frequency data. He has undertaken several government-funded projects related to evaluation of the impact of various government schemes.

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