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Research Article

Development of "iWakka Game" for evaluation of hand dexterity in children with developmental coordination disorder

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ABSTRACT

Our previous study developed a testing and training device, "iWakka," for the adjustability for grasping force. Moreover, we developed "iWakka Game" for autistic patients. In this study, we investigated the applicability of the iWakka Game in children with developmental coordination disorder (DCD). We developed a small grasping body and improved its evaluation method. It was experimented on four children with DCD. Consequently, they completed the evaluation task, which enabled the extraction of hand dexterity characteristics.

1. Introduction

In daily life, hands and fingers play an important role such as grasping a cup and handling chopsticks and forks with an appropriate force. The adjustability for grasping force (AGF), defined in Ref. 1, is one of the motor functions of the fingers and is the ability to grasp an object with an appropriate force. In our previous study, a training and testing device, "iWakka," for the AGF was developed.[1] iWakka comprises a grasping body, "Wakka," and a measurement device. The measurement device comprised a control box, an iPad, and "iWakka Viewer." The control box consists of an amplifier circuit, a microcontroller board, and a BLE module. Figure 1 shows the block diagram of the system. The control box acquires the voltage value of strain signal and transmits it to the iPad via Bluetooth. The iWakka Viewer converts the voltage value into the corresponding grasping force, and shows the grasping force and the target grasping force on the iPad

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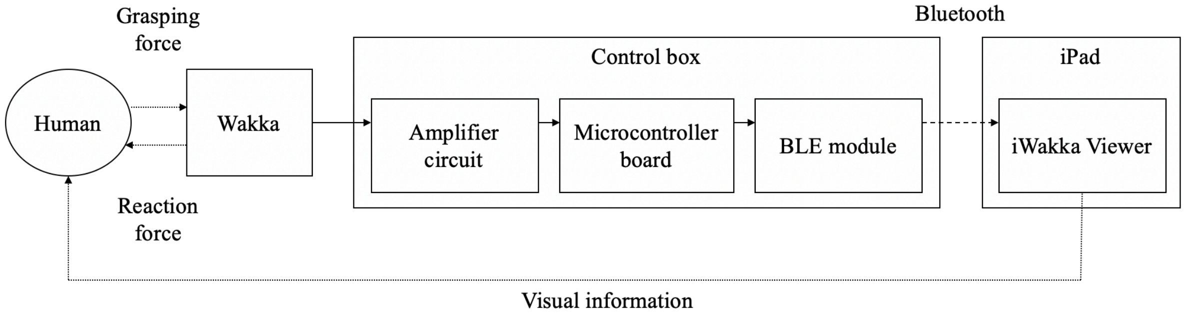

Fig. 1. The block diagram of the system.

screen. They adjusted their grasping force to be closer to the target grasping force. The measurement sampling time was 0.1 s, the measurement range was 0–500 g, and the resolution was 1.6 g. Morita et al. and Toshima et al. observed from Refs. 2 and 3 that adding iWakka to constraint-induced (CI) movement therapy had therapeutic effects in patients after a stroke. To apply iWakka to autistic patients, we also developed "iWakka Game" by improving the game quality of the original one with the Lodz University of Technology and the Center of Autism Diagnosis and Therapy, Lodz, Poland.[4]

Developmental coordination disorder (DCD) is a common neurodevelopmental disorder characterized by impairments in the development of both fine and gross motor skills.[5] Asonitou et al. showed that children with DCD differed significantly from those without DCD performing at a lower level on motor and cognitive tasks.[6] To improve their skills, motor interventions based on virtual reality is preferable for children with DCD because training with Nintendo Wii may be particularly beneficial for children, owing to its motivating aspects.[7] Moreover, Waelvelde et al. revealed that children with DCD were delayed in ball catching and seemed to use different movement strategies compared to younger, typically developing children.[8] Because grasping is the basic ability for various activities, therapists need to evaluate the characteristics of hand dexterity and plan more effective training for their hands. Li et al. designed a marker-less visual-motor tracking system to capture the body to monitor children's behavior in fine motor tasks.[9] They found that the visual movement speed of children with DCD or at risk of DCD is slower than that of typically developing children to focus on the target while their hand movement speed is almost the same. Gonsalves et al. found that 10-12-year-old children with DCD had a slower hand path speed, greater wrist extension, and greater elbow flexion than typically developed children while playing VR games.[10] However, few studies have focused on the characteristics of hand dexterity using game-based devices. The purpose of this study was to investigate the applicability of the iWakka Game to children with DCD and to propose a small-sized device and an evaluation method of the characteristics by subdividing hand dexterity.

2. iWakka Game

The iWakka Game shown in Figure 2, was developed to train and test the grasping force. The brown bird in the iWakka Viewer in Figure 3 rises when the Wakka is gripped and falls when it is released. When a task begins,

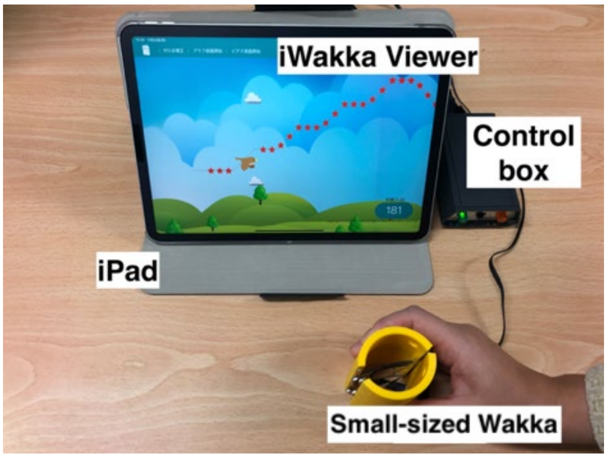

Fig. 2. iWakka Game.

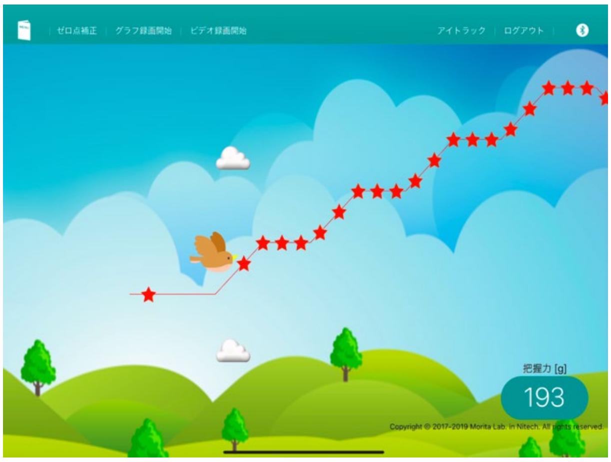

Fig. 3. iWakka Viewer.

the target waveform with red stars moves from the right to the left. The participants were instructed to acquire red stars with the bird's beak by controlling its vertical position and being careful not to contact the cloud placed above and below the bird. The waveform pauses when the bird contacts the cloud, which means that the error between the value of the target waveform and the bird's vertical position exceeds a certain threshold. It resumes when the bird leaves the cloud. This is an assist function that encourages the participants to reduce errors. In other words, the total time of contact is considered to be the assist time. The contact state is referred to as the assisted period.

The therapist determined three setting parameters and a target waveform considering the patient's condition. The three parameters are the distance between the bird and the cloud, the measurement range, and the speed at which the waveform flows from the right to the left. The distance between the bird and the cloud corresponds to the allowable force that does not cause the waveform to pause. The iWakka Game has nine types of waveforms, such as staircase, slope, and sine waves.

The AGF was evaluated from the mean absolute error between the value of the target waveform and the bird's vertical position, which indicates the grasping force by grasping the Wakka.

3. iWakka for Children with DCD

3.1. *Setting parameters and a target waveform*

Table 1. Comparison of the small-sized and original Wakka.

	Small-sized Wakka	Original Wakka
Spring constant [N/m]	5.96×10^2	4.82×10^2
Outer diameter [mm]	54	65
Height [mm]	80	80
Weight [g]	81	112

Before testing using the iWakka Game, a preliminary experiment was conducted to verify its applicability to children with DCD. We determined the three parameters required to complete the tasks appropriately. The distance between the bird and cloud was 100 g. The measurement range was 150–400 g. The speed was 2.97 mm/s from the right to the left of the screen on the iPad.

3.2. *Grasping device*

A small-sized grasping body Wakka was developed to reduce the outer diameter by 83%. This was decided based on the requirements of the therapists and the ratio of the length from the wrist to the tip of the middle finger. The average ratio is 190–220 mm for adults and 150–190 mm for elementary school children. The relationship between the amount of deformation and the force of the device is linear. Table 1 lists a comparison of the small-sized and original Wakka. The spring constant of the small-sized Wakka was 5.96×10^2 N/m, implying that grasping it with a force of 60.8 g produced a deformation of 1 mm.

3.3. *Evaluation method for hand dexterity*

We propose an evaluation method to extract hand dexterity, in addition to the number of stars acquired in the previous study. The waveform shown in Figure 4 was selected to evaluate the characteristics of hand dexterity. Total time was 93 s and the total number of stars was 47.

3.3.1. AGF

We evaluated the AGF for each isometric muscle activity (IC) to hold an object with a constant grasping force, concentric muscle activity (CC) to grip it while increasing the grasping force, and eccentric muscle activity (EC) to release it while decreasing the grasping force. The waveform was subdivided into the IC, CC, and EC sections and the ranges of the grasping forces. The IC was evaluated twice at 150 g. The first evaluation was performed 3 s after the start of the experiment. The CC and EC were evaluated in four sections of the grasping force

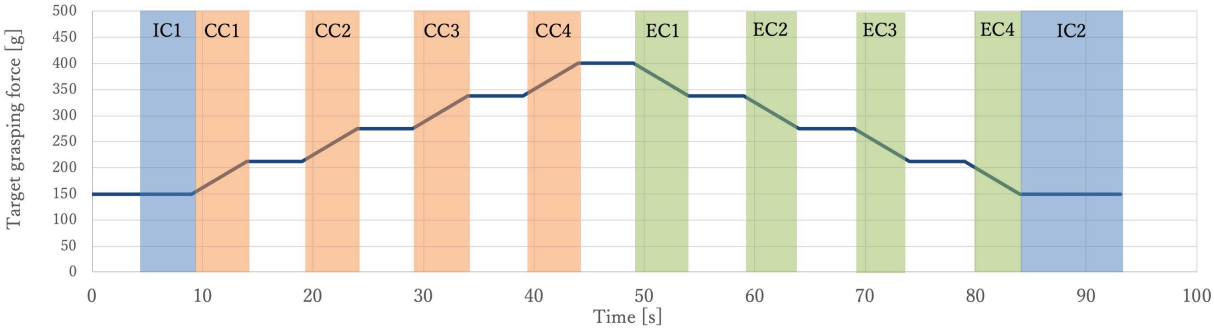

Fig. 4. Target waveform and sections to be evaluated.

range. The average absolute error between the grasping force and target grasping force in each section was calculated as the AGF, as shown in Eq. (1).

$$AGF_{(*)} = \frac{1}{T_{(*)}} \sum_{k=1}^{N_{(*)}} |f_d(k) - f(k)| \text{ [g]} \qquad (1)$$

where $(*)$ denotes the section, $f(k)$ denotes the measured grasping force, and $f_d(k)$ denotes the target grasping force. $T_{(*)}$ denotes the time taken for the section and $N_{(*)}$ denotes the number of data points for the section. T_{IC1} is 6s, T_{IC2} is 9 s, and T for each of the CC and EC sections is 5 s. Because the measurement sampling time is 0.1 s, N_{IC1} is 60, N_{IC2} is 90, and N for each of the CC and EC sections is 50. However, if the bird contacts the cloud, then $T_{(*)}$ and $N_{(*)}$ is extended to the section. This implies that the time of contact with the cloud was included in the calculation. The target grasping force at the start of the contact continues until the end of the contact. The smaller the AGF, the higher is the AGF ability.

3.3.2. AGF in unassisted periods

The longer the assist periods when the bird is in contact with the cloud, the larger the AGF. In other words, when the AGF is evaluated in both the assisted and unassisted periods using Eq. (1), the AGF in the assisted periods significantly affected that in the unassisted periods. Focusing on the fact that the grasping force can be adjusted appropriately even in the unassisted periods, we evaluated the AGF only in the unassisted periods, which is referred as to the AGF_{ua}. The AGF_{ua} was calculated using Eq. (1). Note that $T_{(*)}$ and $N_{(*)}$ do not include the assisted periods and are constant values. Moreover, we also evaluated the assist time for each section. The assist time was defined as the sum of the times the assist was performed in each section.

Table 2. Subject information.

Subject	Age	Sex	Disease	MABC-2 Manual Dexterity
1	6	Male	DCD, and at risk of Dysarthria	6
2	5	Male	DCD	6
3	7	Male	DCD, ASD, and ADHD	10
4	9	Male	At risk of DCD	5

4. Experiments and Results

4.1. *Subjects*

The four patients are listed in Table 2. All patients were diagnosed with DCD or were at a risk of developing DCD. The iWakka was used with the dominant hand. The MABC-2 is designed to identify and describe impairments in the motor performance of children and adolescents 3 to 16 years old.[11] Three types of assessment items were used. The maximum score for each item was 19. Manual dexterity is one of them, and the test content for each is different for the three bands: 3 to 6, 7 to 10, and 11 to 16 years old.

4.2. *Characteristics of hand dexterity*

Figures 5, 6, 7, and 8 show the AGF and AGF_{ua} of Subjects 1, 2, 3, and 4, respectively. Figure 9 shows the assist time of all subjects. Figure 5 shows that the AGF and AGF_{ua} in all EC sections were greater than in all CC

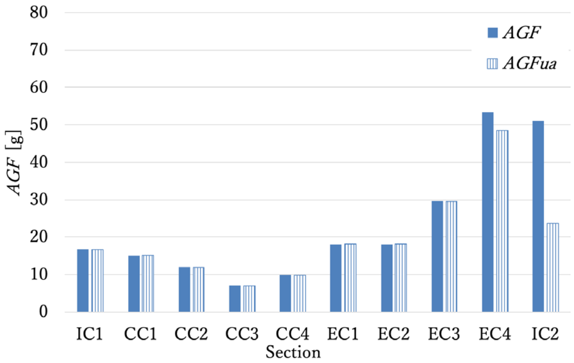

Fig. 5. *AGF* of Subject 1.

sections respectively. This means that Subject 1 was worse at decreasing the grasping force than at increasing it. Figure 9 shows that Subject 1 required assistance only in the EC4 and IC2 sections. Therefore, the AGF and AGF_{ua} were the same except in the EC4 and IC2 sections. On the other hand, Figure 9 shows that Subject 2 required assistance in the CC1, CC2, CC3, and EC1 sections. This means that Subject 2 was worse at increasing the grasping force than at decreasing it. Figure 6 shows that the AGF in the CC1, CC2, CC3, and EC1 sections were greater than the AGF_{ua} respectively. This means that with assistance, Subject 2 was able to adjust his grasping force in the unassisted periods. Focusing on IC sections, the AGF of Subject 1 in the IC2 section was greater than in the IC1 section and the assist time occurred in the EC4 and IC2

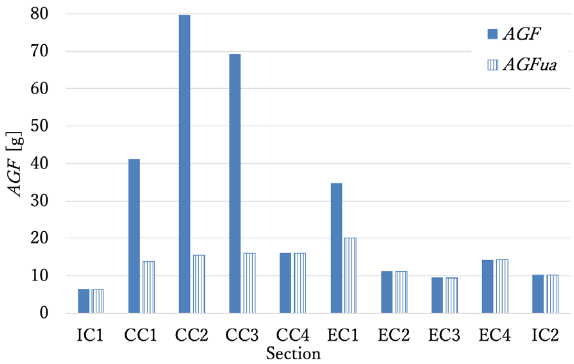

Fig. 6. *AGF* of Subject 2.

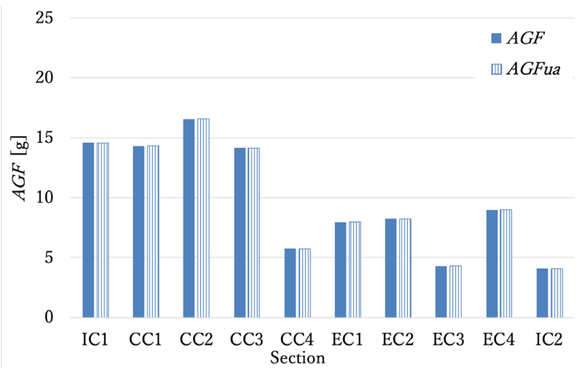

Fig. 7. *AGF* of Subject 3.

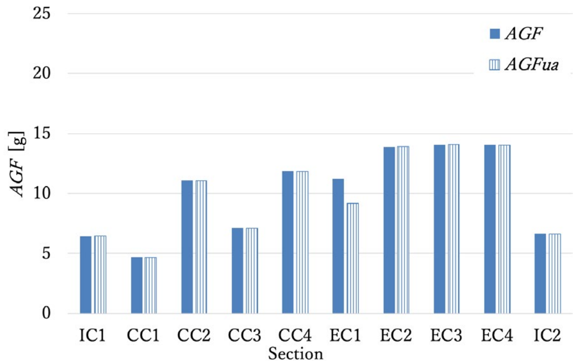

Fig. 8. *AGF* of Subject 4.

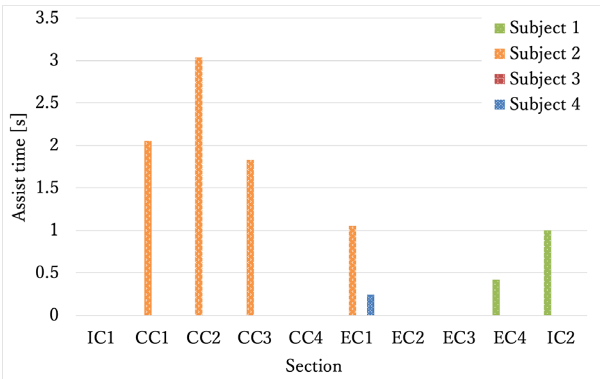

Fig. 9. Assist time of each section.

Table 3. Number of stars acquired.

Subject	Number of stars acquired
1	32
2	32
3	35
4	41

sections. It indicates that he had a low ability to hold at 150 g after decreasing the grasping force. The AGF and AGF_{ua} of Subject 3 were the same shown in Figure 7 because he did not need any assistance in all sections. This means that he could adjust their grasping force appropriately without causing significant errors. Subject 4 needed little assistance because the assist time is 0.2 s at EC1. AGF_{ua} was 2.1 g smaller than AGF at EC1 shown in Figure 8. It was possible to extract hand dexterity by comparing different sections of the AGF. However, the AGF was insufficient because it couldn't evaluate the effect of the assist. Using the AGF_{ua} and assist time in addition to the AGF allowed us to evaluate the effect of the assist.

Table 3 lists the number of stars acquired. The number of Subjects 1 and 2 was the same. However, they had different hand dexterity characteristics, as shown in Figure 5, 6 and 9. Subject 4 acquired more stars than Subject 3. Consequently, it was observed that assistance was effective in helping subjects acquire stars in the weak sections.

5. Conclusion

We observed that the iWakka Game was applicable not only to autistic patients but also to children with DCD, aged 5–9 years, by using the small-sized grasping device, Wakka, and appropriate setting parameters. Moreover, the proposed evaluation method enabled the extraction of hand dexterity characteristics for each child. By subdividing the AGF into the IC, CC, and EC sections, and by considering assistance, we were able to evaluate the subjects' hand dexterity from various perspectives compared to the evaluation by the number of stars. They had different characteristics of holding, gripping, and releasing in each range of grasping force, which they were not good at. Improving each ability can enhance the hand movements necessary for daily life. This result leads therapists to plan more effective hand dexterity training.

Since the applicability of the iWakka Game to children with DCD was demonstrated, our future studies will involve collecting data on healthy children by age and on children with DCD by age and disability to gain knowledge.

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References

1. Y. Morita, S. Nakajima, N. Sato, K. Yasaki, "Quantitative Evaluation System of Adjustability for Grasping Force, Journal of the Japan Society for Welfare Engineering, Vol. 18, Subject 2, pp. 5-10, 2016. (in Japanese)
2. Y. Morita, K. Ando, M. Nomura, K. Toshima, T. Tamaru, "Verification of Usefulness of Testing/Training Device of Adjustability for Grasping Force on Hemiplegic Patients after Stroke", Transactions of the Society of Instrument and Control Engineers, Vol. 55, Subject 1, pp. 78-84, 2018. (in Japanese)
3. K. Toshima, Y. Morita, T. Tamaru, "Study on Dexterity Movement Training by Grasping Device (iWakka) Used on Upper Limb Paralysis after Stroke and Its Combined Effect with CI Therapy," 13th International Society of Physical and Rehabilitation Medicine World Congress (ISPRM 2019), P3–995, 2019.
4. M. Nomura, N. Kucharek, I. Zubrycki, G. Granosik, Y. Morita, "Adjustability for Grasping Force of Patients with Autism by iWakka: A Pilot Study", 2019 12th International Workshop on Robot Motion and Control (RoMoCo), pp. 50-55, 2019.
5. D.F.A.A. Derikx, M.M. Schoemaker, "The Nature of Coordination and Control Problems in Children with Developmental Coordination Disorder during Ball Catching: A Systematic Review", Human Movement Science, Vol. 74, p. 102688, 2020.
6. K. Asonitou, D. Koutsouki, T. Kourtessis, S. Charitou, "Motor and cognitive performance differences between children with and without developmental coordination disorder (DCD)," Research in Developmental Disabilities, vol. 33, no. 4, pp. 996-1005, 2012.
7. J.L. Cavalcante Neto, B. Steenbergen , E. Tudella, "Motor intervention with and without Nintendo® Wii for children with developmental coordination disorder: protocol for a randomized clinical trial" Trials, vol. 20, no. 1, 794, 2019.
8. H. Van Waelvelde, W. De Weerdt, P. De Cock, B.C.M. Smits-Engelsman, and W. Peersman, "Ball Catching

Performance in Children with Developmental Coordination Disorder," Adapted Physical Activity Quarterly, vol. 21, no. 4, pp. 348-363, 2004.

9. R. Li, B. Li, S. Zhang, H. Fu, W. Lo, J. Yu, C. Sit, D. Wen, "Evaluation of the fine motor skills of children with DCD using the digitalised visual-motor tracking system," The Journal of Engineering, vol. 2018, no. 2, pp. 123-129, 2018.
10. L. Gonsalves, A. Campbell, L. Jensen, L. Straker, "Children With Developmental Coordination Disorder Play Active Virtual Reality Games Differently Than Children With Typical Development," Physical Therapy, vol. 95, no. 3, pp. 360-368, 2015.
11. T. Brown, A. Lalor, "The Movement Assessment Battery for Children—Second Edition (MABC-2): A Review and Critique", Physical & Occupational Therapy In Pediatrics, vol. 29, no. 1, pp. 86-103, 2009.

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