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Original Article

# Relationship Between Eye–Hand Coordination and Learning of Crutch Use: A Dual-Task Paradigm

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**Purpose:** The aim of this study is to explore the relationship between eye-hand coordination and the attentional demands of bilateral axillary crutch use.
**Methods:** Sixteen young participants completed five crutch training sessions based on a four-point gait. The percentiles for the category "Aiming and Catching" on the Movement Assessment Battery of Children–second version was examined at baseline to serve as the index of eye-hand coordination. Performance of dual tasks (walking with a crutch and mathematical computation) was evaluated repetitively at baseline and during training sessions. The attentional demands of crutch use were indicated by the decrement in mathematical performance during the execution of dual tasks.
**Results:** There was a decrement in mathematical performance during the execution of dual tasks on the first two baseline tests ($p = .001$). This decrement disappeared during the training sessions. There was a fair and negative relationship between eye-hand coordination and attentional demands of crutch use ($r = -.274$, $p = .004$).
**Conclusion:** It is recommended that eye-hand coordination be assessed and patients undergo practice sessions before using their walking aid in real life. More patient populations and broader assessments of coordination should be included in future studies.

**Keywords:** attentional demand, axillary crutch, dual-task decrement, eye-hand coordination, four-point gait

## 1. Introduction

Assistive devices, such as canes, walkers, and crutches, are often provided to patients during physiotherapy to ease the task of ambulation. These walking aids provide biomechanical stability, reduce lower limb loads, generate propulsion and braking forces during walking, and enhance somatosensory cues[1]. However, walking aids can also cause adverse effects, such as increased attentional demands or biomechanical destabilization, unless countered by anticipatory postural adjustments. Thus, the risk of falls may increase with the use of walking aids[1].

As most patients are prescribed a walking aid for the first time they must learn how to use it properly. Lucki et al.[2] explored the influence of experience using a walker on mobility tests among healthy elderly participants. As experience increased, performance on the Timed Up and Go test improved. However, few studies have examined the factors that mediate the learning process of a specific type of walking aid.

One factor that may influence a patient's ability to function with a walking aid is eye-hand coordination. The use of an aid requires adaptation to a different walking pattern, i.e., two-point gait, three-point gait, four-point gait, swing-to gait, or

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swing-through gait. With these gait patterns, patients exert effort to manipulate a walking device with the upper extremities and maintain proper positioning, taking into consideration the environment, walking device, and body. Adapting to a new gait pattern also results in neuromotor demands[1].

Another factor that may influence a patient's ability to function with a walking aid is the attentional demands associated with the appropriate use of a prescribed device, which is usually investigated via a dual-task paradigm. In this paradigm, a postural task serves as the primary task and the simultaneously performed cognitive task serves as the secondary task[3]. Changes in performance on the secondary task are employed to draw conclusions about the attentional demands of the primary task. Wright et al.[4] first used the dual-task paradigm to probe the attentional demands associated with walking aids in a group of healthy young and middle-aged participants. They found stepwise deteriorating performance of the secondary task while walking alone, walking with rolling walker, and walking with standard walker. Wellmon et al.[5] studied three groups of elderly adults: those who do not use aids, those who ambulate with cane, and those who ambulate with rolling walker. They found significantly deteriorated performance of the secondary task between the group that does not use aids and the one that uses a rolling walker. The attentional demands associated with using crutches have yet to be described.

The two individual factors mentioned above can be measured independently to assess an individual's capacity to use a walking aid. Eye-hand coordination can be evaluated via a commercialized assessment battery and attentional demands via a dual-task paradigm. Their relationship in the walking aid learning process has not been previously explored. Therefore, in this pilot study, we aimed to investigate the relationship between eye-hand coordination and learning of crutch use. Eye-hand coordination was assessed only once at baseline because it was assumed to be relatively stable over time. Previous longitudinal studies have documented a reduction in attentional demands of postural tasks in elderly adults[2], patients with amputation[6], and patients with stroke[7]. Thus, the learning of crutch use was indicated in a dual-task paradigm and measured repetitively. The relationship between baseline eye-hand coordination and changes in dual-task performance with crutch use over time was examined on correlation analyses. We predicted (1) positive attentional demands of crutch use as indicated by the decrement in secondary task performance during the execution of dual tasks, with attentional demands decreasing over time, and (2) negative relationship between eye-hand coordination and attentional demands of crutch use, i.e., with better coordination, attentional demands of crutch use decrease.

## 2. Materials and Methods

### 2.1. Participants

We recruited 16 young participants who were enrolled in a Bachelor's degree program in physiotherapy. The exclusion criteria were: (1) a history of cane or crutch use, apart from physiotherapy training courses and (2) orthopedic condition in the recent month that may impact postural performance. All participants provided written informed consent and this study was approved by the Institutional Review Board of Chung Shan Medical University Hospital in accordance with the Helsinki Declaration.

### 2.2. Procedures

The subjects participated in six experimental sessions on consecutive days but separated by one weekend. The first session was for baseline tests of eye-hand coordination and ability to perform dual tasks. The second to sixth sessions were for crutch training and the ability to perform dual tasks was tested after each of these sessions.

Eye-hand coordination was tested only once, during the baseline session, based on two items from the Movement Assessment Battery of Children–second version (M-ABC2)[8]. In the category of "Aiming and Catching" for the age band 11–16 years, "catching with one hand" and "throwing at wall target" were used. For the former, participants were asked to throw a tennis ball at a wall 2 m away. When the ball bounced back after hitting the wall, and before it bounced on the floor, subjects were to catch it with one hand. Five practice trials were followed by 10 formal trials for each hand. The cumulated successful trials for each hand were recorded. For the latter, subjects were asked to throw a tennis ball at a round target ( diameter 25.5 cm) on the wall, placed at the level of the subject's head and a distance of 2.5 m, using the preferred hand. Five practice trials were followed by 10 formal trials. The number of successful trials in which the tennis ball hit the target was recorded.

Dual-task testing was conducted thrice during baseline session to familiarize subjects with the testing protocol. The ability to perform dual tasks was examined once after each training session. Previous studies have demonstrated that tasks involving internal interfering factors, e.g., mathematical tasks, disturb walking performance more than those involving external interfering factors[9] and, while combing while walking better predicts falls in the elderly population[10], a mathematical task was chosen as the secondary task. The participants were first asked to continuously subtract by three from a randomly selected number between 50 and 100 while standing for 30 s. This step served as the single mathematical task. Walking speed was then measured with GAITRite® (CIR Systems, Inc. New Jersey, USA), which included a 4.26 m electronic walkway that was extended with yoga mats by 1.5 m at each end for gait acceleration and deceleration. During the single walking task, crutch walking with four-point gait was performed along the GAITRite walkway. During performance of dual tasks, crutch walking was conducted concurrently with the mathematical task. The participants were instructed to prioritize the mathematical task and the four-point-gait and not to sacrifice accuracy for speed. Single and dual walking tasks were executed thrice, with their order determined based on a random table.

One-to-one crutch training was performed from the second to the sixth sessions. The subjects were offered a pair of axillary crutches, adjusted to their height. Crutch training was conducted with four obstacle cones positioned 100 cm apart, forming a double-S-shaped path. During each session, three three-minute training periods were arranged with one-minute break in between. The participants were taught to walk with a four-point gait, i.e., one crutch was used to take the first step forward, followed by the opposite leg, the second crutch, and the other leg. The four-point gait involves bilateral movements and provides a slow stable gait as three points of floor contact are maintained. It is often used in physiotherapy for patients with poor balance or muscle weakness.

### 2.3. Data analysis and statistics

According to the norms of the M-ABC2 16-year-old age band, cumulated successful trials of the two items "catching with one hand" and "throwing at wall target" were converted into percentiles for the category "Aiming and Catching," which served as the determinant of eye-hand coordination for each subject. The higher the score, the better the coordination. Walking speed was output by GAITRite and averaged over three trials. Mathematical performance was defined as the number of correct answers per second and averaged over three trials. The dual-task decrement of mathematical performance was calculated as follows to indicate the attentional demands of crutch use: (single-task performance − dual-task performance)/single-task performance × 100%[11]. The result indicated the degree of performance decrement during execution of dual tasks. A positive value corresponded to impeded performance and a negative value corresponded to facilitated performance.

Data were analyzed with SPSS (PASW Statistics 18.0, SPSS Inc., Chicago, Illinois). One-sample Kolmogorov–Smirnov tests were conducted to ensure the normal distribution of each variable. Separate one-way repeated measures ANOVAs were performed to examine the changes over time in walking speed, mathematical performance, and dual-task decrement of mathematical performance. Greenhouse-Geisser correction to the degrees of freedom was used when there were violations of sphericity. Preplanned polynomial or repeated contrasts were compared between sessions and Bonferroni adjustments were applied to correct multiple comparisons. The correlation between eye-hand coordination and dual-task decrement of mathematical performance was evaluated on Pearson's correlation analysis. Correlation coefficients of less than 0.25, between 0.25 and 0.50, between 0.50 and 0.75, and greater than 0.75 indicated weak relationship, fair relationship, moderate-to-good relationship, and good-to-excellent relationship, respectively[12]. Significance level was set at 0.05.

## 3. Results

One subject was hospitalized during the experimental period and did not participate in the fourth or fifth training sessions. The average age of the three male and 13 female subjects was 21.95 ± 1.82 years. Average body weight and height were 53.25 ± 10.61 kg and 160.25 ± 7.89cm, respectively. The percentiles of M-ABC2 "Aiming and Catching" ranged from 0.5 to 95% with an average of 28.93 ± 3.15% (Table 1).

**Table 1. Demographics of participants**

| variable | N or mean ± SD |
|---|---|
| sex (male/female, N) | 3/13 |
| age (years) | 21.95 ± 1.82 |
| body weight (kg) | 53.25 ± 10.61 |
| body height (cm) | 160.25 ± 7.89 |
| M-ABC2 (%) | 28.93 ± 31.15 |

N=number, SD=standard deviation, M-ABC2= percentiles of "Aiming & Catching" on Movement Assessment Battery of Children–second version

The average walking speed for the three baseline tests and the five training sessions during performance of a single task, i.e., crutch walking, were 32.79 ± 10.19, 36.96 ± 10.10, and 40.56 ± 11.25 cm/s (baseline) and 41.21 ± 14.94, 45.92 ± 14.35, 48.55 ± 14.87, 51.50 ± 19.27, and 55.31 ± 20.98 cm/s (training), respectively. Repeated measures ANOVA revealed a significant main effect of time ($F_{7,98}$ = 14.415, p < .001) and planned contrasts indicated a significant linear increase ($F_{1,14}$ = 21.405, p < .001). The average values of walking speed for the three baseline tests and the five training sessions during performance of dual tasks, i.e., crutch walking and mathematical task, were 23.45 ± 6.24, 28.73 ± 5.70, and 31.20 ± 7.21 cm/s (baseline) and 31.89 ± 10.13, 35.15 ± 9.63, 41.03 ± 11.22, 43.24 ± 14.09, and 47.36 ± 17.84 cm/s (training), respectively. Repeated measures ANOVA showed a significant main effect of time ($F_{7,98}$ = 24.427, p < .001) and planned contrasts revealed a significant linear increase ($F_{1,14}$ = 37.781, p < .001).

The average number of correct mathematical answers per second for the baseline test and the five training sessions during performance of a single task, i.e., while standing quietly, were 0.64 ± 0.21 (baseline) and 0.77 ± 0.17, 0.85 ± 0.23, 0.86 ± 0.15, 0.94 ± 0.19, and 1.00 ± 0.26 (training), respectively. Repeated measures ANOVA revealed a significant main effect of time ($F_{5,70}$ = 22.461, p < .001) and planned contrasts revealed a significant linear increase ($F_{1,14}$ = 91.091, p < .001). In terms of the number of correct mathematical answers per second during performance of dual tasks, i.e., during crutch walking, the average values for the three baseline tests and the five training sessions were 0.59 ± 0.18, 0.72 ± 0.18, and 0.76 ± 0.16 (baseline) and 0.83 ± 0.18, 0.87 ± 0.19, 0.99 ± 0.22, 1.03 ± 0.27, and 1.08 ± 0.26 (training), respectively. Repeated measures ANOVA indicated a significant main effect of time ($F_{7,84}$ = 22.857, p < .001) and the pre-planned contrasts showed a significant linear increase ($F_{1,12}$ = 46.478, p < .001).

The average values of dual-task decrement of mathematical performance for the three tests at baseline and the five training sessions were 9.65 ±

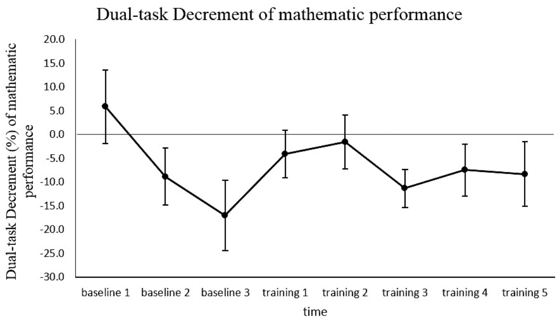


**Fig. 1.** Dual-task decrement (%) of mathematical performance, i.e., correct answers per second, was computed as single-task performance minus dual-task performance and normalized to single-task performance. A positive value indicates impeded performance due to execution of dual tasks, whereas a negative value indicates facilitated performance due to execution of dual tasks. Error bars represent ± 1 SEM. The mathematical performance decrement due to execution of dual tasks decreased during the first two baseline tests (p = .001) and disappeared during the training sessions.

25.85, −9.92 ± 25.56, and −17.72 ± 31.24 % (baseline) and −5.84 ± 18.81, −2.95 ± 22.93, −12.44 ± 16.15, −9.75 ± 22.25, and −9.96 ± 28.50 % (training), respectively (Fig. 1). Performance deteriorated from execution of single task to execution of dual tasks, i.e., positive, only during the first test at baseline. Mathematical performance was better during execution of dual tasks than during execution of single task during all other sessions. Repeated measures ANOVA revealed no significant main effect of time ($F_{7,84} = 1.905$, $p = .160$), but the planned repeated contrast showed a significant difference between the first and second baseline tests ($p = .001$).

Pearson’s correlation analysis revealed a negative and fair relationship between eye-hand coordination and dual-task decrement of mathematical performance ($r = −.274$, $p = .004$; Fig. 2).

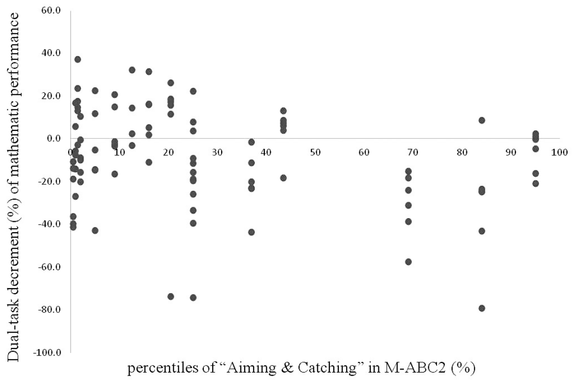


**Fig. 2.** Scatter plot between dual-task decrement of mathematical performance and percentiles of "Aiming & Catching" on Movement Assessment Battery of Children–second version (M-ABC2). A significant and negative relationship is evident ($r = -.274$, $p = .004$).

## 4. Discussion

Previous dual-task studies have demonstrated attentional demands of ambulation with a walker[4] and a cane[5]. This study was the first to document the attentional demands of ambulation with bilateral axillary crutches. The results showed positive dual-task decrement of mathematical performance during the first baseline session. Mathematical performance while ambulating with axillary crutches was worse than that while standing quietly.

Our longitudinal results revealed a gradual decrease in the attentional demands of crutch use over the three baseline sessions. This finding was consistent with that of Lucki et al.[2], who investigated the attentional demands of walker use in healthy elderly people. Similarly, this result agreed with that of Hume et al.[13], who examined the relationship between training time and gymnastic performance. However, the dual-task decrement of mathematical performance turned negative and did not decrease over time during the five training sessions. After practice trials, our participants were mostly able to follow our instructions to prioritize the mathematical task over walking speed. The results showed consistently lower walking speed while ambulating with axillary crutches and simultaneously conducting mathematical task, compared with ambulation using axillary crutches alone. Performing two attention-demanding tasks simultaneously not only causes competition for attention, but also challenges the central nervous system in terms of prioritizing the two tasks[14]. The task prioritization model presents a hierarchy in the allocation of attentional resources, which is dependent on the complexity of postural and cognitive tasks, instructions, and environmental context[15].

Our results also illustrated a negative relationship between the dual-task decrement of mathematical performance and eye-hand coordination. The relationship between eye-hand coordination and motor learning has been well-established in sports. Kioumourtzoglou et al.[16] compared the eye-hand coordination of three groups of rhythmic gymnasts and showed a significant difference between the oldest and youngest groups. Hume et al.[13] conducted a correlation analysis and documented eye-hand coordination as one of the significant correlates of attainment of competitive advantage by female gymnasts. Faber et al.[17] implemented a generalized estimating equation analysis and found that among table tennis players perceptual motor skill explains 53% of the variance in subsequent competition results over the following 2.5 years. Moreover, Yeh et al.[18] reported the superior learning ability of rhythmic gymnasts in balancing tasks in contrast to controls.

There are some limitations to this study, such that the results should be cautiously applied. First, our results were based only on young and healthy participants, thus limiting their generalization. In future studies, elderly or pathological populations in need of walking aids should be investigated. Second, the coordination measure was only eye-hand coordination and only the oldest age band of up to 16.99 years could be referenced based on the M-ABC2. However, the percentiles of our participants (aged 21.95 ± 1.82 years) did not show a ceiling effect. Rather, they were scattered between .5 and 95%. In future studies, broader assessments of coordination, such as inter-limb or whole-body coordination, should be included to investigate the relationship between eye-hand coordination and attentional demands of crutch use.

In conclusion, in healthy young subjects using bilateral axillary crutches to walk straight, there are attentional demands of crutch use, which disappear after two practice trials with walking speed decrement. In addition, there is a negative relationship between the attentional demands of crutch use and eye-hand coordination. Based on the results, assessment of patients' eye-hand coordination before a walking aid is prescribed and provision of practice sessions before patients use their walking aid in real life are recommended. Real-life walking conditions, e.g., obstacle walking, encountered by elderly or pathological populations, and broader assessments of coordination, such as inter-limb or whole-body coordination, should be included in future studies.

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