Effects of Task Complexity on Reaction Time and Movement Kinematics in Elderly People

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KEY WORDS
• coordination
• motor control
• task performance and analysis

OBJECTIVE. In clinical practice, occupational therapists identify characteristics or demands of a task and, to improve coordination or problem solving ability, grade it along the complexity dimension. Effects of increased complexity of functional tasks have not been studied to date. The purpose of this study was to continue to examine the characteristics of occupation by testing the effect of task complexity on motor performance in elderly people.

METHOD. A counterbalanced repeated-measures design was used. Twenty-eight elderly people without motor problems (9 men, 19 women) performed checker game moves ranging from one to four steps. Only the first segment of movement from start position to the first designated place was kinematically analyzed and compared among the four conditions because it has been shown in earlier studies that differences in strategy are apparent from the first segment.

RESULTS. Generally, the more complex moves elicited higher peak velocity (indicating greater force employed, $F[3,72] = 3.45, p = .0210$) and more movement units (indicating a less smooth and less efficient movement, $F[3,72] = 4.71, p = .0047$) than a simple move.

CONCLUSION. The results indicate that in this study, task complexity affects forcefulness and smoothness of motor performance, supporting the practice of activity analysis and gradation along the complexity dimension in occupational therapy. When treating elderly people in clinics, therapists may increase the number of steps within a task to facilitate the force embedded in movement, or decrease the number of steps to facilitate smooth and economical movement.


In occupational therapy, activity analysis serves as the critical precursor to the design of activity adaptations required to optimize clients’ performances (Levy, 1990). As daily life involves the implementation of tasks with various levels of complexity, task complexity is suggested as one dimension in the conceptualization of occupational performance (Trombly, 1995). In addition, task complexity is recognized as a factor that constrains occupational behavior (Barris, Kielhofner, Levine, & Neville, 1985; Kielhofner, 1995). In clinical practice, therapists identify procedures of a task and grade it along the complexity dimension (Lamport, Coffey, & Hersch, 1993; Trombly & Radomski, 2002). According to Barris et al. (1985), task complexity is defined as the number of movement steps required to execute a task. However, despite the notion of task complexity in both theories and clinical practice, no empirical studies in occupational therapy have investigated the effect of task complexity on motor performance. In the area of motor behavior sciences, a similar topic, response complexity effect, has been widely examined. That literature may shed light on the issue of task complexity in our profession.
Response Complexity Effect

In his review paper, Christina (1992) stated that “The response complexity effect refers to the finding that, within limits, the time needed to prepare to initiate a previously learned movement sequence that must be executed as rapidly and accurately as possible becomes longer as the response becomes more complex” (p. 219). The response complexity effect was first investigated by Henry and Rogers (1960). In their study, healthy college students were asked to perform three movements of varying degrees of complexity. Response A was a simple finger lift; Response B was a forward and upward movement of the right hand to grasp a ball. Response C had three movement parts, involving a finger lift and two arm movements to strike balls. The reaction time was significantly longer for the complex response (159, 195, and 208 ms for the Response A, B, and C, respectively).

Henry and Rogers’ (1960) findings were confirmed by many subsequent studies (see Christina [1992] for a review). The increase of reaction time, however, is not unlimited. In the studies varying tasks from one to more than three steps, it was usually found that the greatest increase of reaction time occurred between one- and two-step (or three-step) tasks (Fischman, 1984; Garcia-Colera & Semjen, 1987).

The lack of further increase in reaction time after a certain number of steps has been attributed to the occurrence of “online” control. That is, part of the movement was planned during the movement execution as opposed to entirely beforehand; therefore, the mental activity required before execution did not have to increase additionally (Etnyre, 1992; Garcia-Colera, & Semjen, 1987; Rosenbaum, Hindorf, & Munro, 1987; Smiley-Oyen, & Worringham, 1996). However, reaction time alone is insufficient to verify the presence of online control; more sensitive, direct measures would be reflected in movement kinematics.

Movement Kinematics and Task (Response) Complexity

Kinematics refers to the description of the spatial and temporal aspects of motion (Hamill & Knutzen, 1995). Kinematic analysis has been used to understand the underlying movement strategies. Kinematic variables include movement time, movement units, peak velocity, acceleration time, deceleration time, and percentage of movement time to peak velocity. Movement time, the duration of execution of a movement, reflects the overall speed of a movement, as a faster movement would result in shorter movement time.

When the hand reaches toward a target, it generally accelerates first and then decelerates to correct the trajectory as it approaches the target (Georgopoulos, 1986). Peak velocity, the highest instantaneous velocity during the movement, occurs as the point of changeover from the acceleration to deceleration phase of the reach (Schmidt & Lee, 1998). Peak velocity is regarded as being correlated with the force of a movement (Nelson, 1983).

In addition, it is generally considered that the acceleration phase in the velocity profile corresponds to the preplanning part of a movement and the deceleration phase the online adjustment part. Thus, a more preplanned movement would have longer acceleration time, shorter deceleration time, or a higher percentage of movement time to peak velocity, as compared to a more online controlled movement (Nagasaki, 1989).

A movement unit is defined as one acceleration phase and one deceleration phase (Brooks, Cooke, & Thomas, 1973). Preplanned movement would display a smooth, single-peaked velocity profile, therefore being characterized by one movement unit. In contrast, guided movement would have a discontinuous, multiple-peaked velocity trace with multiple movement units (Brooks & Watts, 1988). Additional movement units in guided movements are considered to be adjustments prompted by sensory feedback (Brooks et al.). In addition, the number of movement units informs us about the smoothness and efficiency of a movement; fewer movement units indicate a smoother and more efficient movement.

In the 1990s, kinematic analysis began to be included in some studies of movement complexity. In consideration of the fact that previous research on response complexity effect usually made participants move as rapidly as possible (e.g., Fischman, 1984; Fischman & Yao, 1994; Garcia-Colera & Semjen, 1987), van Donkelaar and Franks (1991a, 1991b) suspected that the findings of increased reaction time in more complex conditions might not be replicated if participants were allowed to move more slowly. Therefore, they employed reaction time and kinematic measures to examine the effect of movement complexity under different movement speeds. In their study, healthy college students were required to perform a repetitive elbow flexion–extension movement either as fast as possible or at a considerably slower speed. They found that at the quickest speed, reaction time increased in a linear fashion as movement complexity increased, while movement units were limited to only one. In contrast, at a slower speed, reaction time did not increase significantly with increases in task complexity, but movement units increased. These findings suggest that the effect of movement complexity is moderated by movement speed. That is, movement that has to
be executed as quickly as possible requires programming in advance, and therefore reaction time increases as the condition becomes more complex; however, movement that is executed slowly allows online control, and thus movement units increase in more complex conditions.

In addition to reaction time and movement units, another two studies measured movement time and peak velocity of motor performance under discrete and reversal conditions (Adam, van der Bruggen, & Bekkering, 1993; Lajoie & Franks, 1997). In the discrete condition, young college students performed a one-step movement by moving a stylus from the start position to the first target. In the reversal condition, the participants performed a two-step movement by moving the stylus from the start position to the first target and then backward to a second target. Results of both studies showed that movement time was shorter and peak velocity was higher in the first part of the reversal (two-step) movement than in the simple (one-step) movement. The comparative slowness in the simple movement was attributed to the observation that the simple movement required a movement stop as imposed by the target, while the reversal movement did not require a movement stop but allowed a fast movement reversal. The findings suggest that the presence of a movement stop should be taken into account in the prediction of how task complexity affects movement kinematics.

Finally, research on elderly people suggests that as adults age, they experience slowing in psychomotor behaviors. By comparing motor performance between elderly and younger people, some researchers indicated elderly people required longer time to initiate movement, moved more slowly (Weir, MacDonald, Mallat, Leavitt, & Roy, 1998), and their movement was often characterized by more movement units, implying a greater reliance on guidance (Morgan et al., 1994). Studies further found that as task demands increased, the decline of performance in elderly people was more obvious than that in younger people. Light and Spirduso (1990) manipulated the complexity of a microswitch pressing task by altering the number of body sides and the number of fingers involved. They reported that elderly participants were more sensitive to small changes in movement complexity than younger participants, as indicated by reaction time. Goggin and Meeuwen (1992) employed aiming tasks with various movement distances and target widths, and found that elderly participants were significantly slower and more affected by long movement distance and small target width than younger participants.

The purpose of this study was to examine the effect of task complexity on reaction time and movement kinematics in elderly people. Although review of motor behavior sciences literature supports the pursuit of this line of inquiry, it is also noted that some aspects of those studies have to be adapted to match the concern of occupational therapy. First, the tasks involved in the reviewed literature are more laboratory, or contrived, tasks (e.g., tapping tasks) that are seldom encountered in daily situations. In the present study, an ecologically relevant task, a checker game task, was employed because it involves familiar objects available on the market and it is a game that people are likely to have played. Second, in the reviewed response complexity effect studies, participants were usually asked to move as fast as possible. In the present study, participants moved at self-paced speeds, because this is the way people perform tasks in their daily life. Third, most of the response complexity studies included young college students as participants. Although research suggests that elderly people are more sensitive to changes in task demands than younger people, no kinematic studies on task complexity have been conducted in elderly people. Since elderly people constitute a rapidly growing population in the United States and also represent a large group treated by occupational therapists (Clark et al., 1997), it is important to evaluate how task complexity affects elderly people’s performance in daily tasks.

Hypotheses

1. There would be no statistically significant differences of reaction time among the conditions with different levels of complexity.
2. Movement in a simple condition would be characterized by significantly fewer movement units than movement in a more complex condition.
3. Movement in the one-step condition would be characterized by significantly longer movement time than movements in the other conditions.
4. Movement in the one-step condition would be characterized by significantly lower peak velocity than movements in the other conditions.

The first and second hypotheses were formulated according to the findings of van Donkelaar and Franks (1991a, 1991b), with the assumption that elderly participants’ self-pace speeds would be similar to the slower speed of the young college students in those studies. The third and fourth hypotheses were proposed on the basis of the findings of Adam et al. (1993) and Lajoie and Franks (1997), in consideration of the fact that in the one-step condition, a movement stop was required at the end of movement, while in the other conditions, a movement stop was not required until the last step was completed.
Method

Study Design

A counterbalanced repeated-measures design was used (Rosenthal & Rosnow, 1991). Each participant was randomly assigned to one of the following sequences: ABCD, BCDA, CDAB, and DABC, where A, B, C, and D represent the conditions of one step, two steps, three steps, and four steps, respectively.

Participants

A sample of convenience composed of 28 elderly people (9 males, 19 females) participated in this study. The participants self-reported to have normal or corrected-to-normal vision and no known neurological disorders affecting the motor system. The participants' ages ranged from 60 to 78 years ($M = 69.67$, $SD = 4.46$). Twenty-four of the participants were right-handed; 4 participants were left-handed.

Materials and Instrumentation

An 18” x 18” checkerboard with 2” x 2” squares, and checkers (1 1/4” in diameter, 1/5” in height, 7.5 g in weight) were used.

A three-sensor OPTOTRAK™ 3020 system (Northern Digital, Inc., Waterloo, Ontario, Canada) connected with the Dell OPTIPLEX XM 575 computer was used for recording three-dimensional movement kinematics, including movement units, movement time, peak velocity, and percentage of movement time to peak velocity occurred. A trigger connected with the computer was used to give the participant a visual start signal while simultaneously beginning data collection. One infrared light emitting diode (IRED) was attached on the ulnar styloid on the participant's dominant side to record arm movement. This marker placement was parallel to the setup in the classic study by Marteniuk, MacKenzie, Jeannerod, Athenes, and Dugas (1987) that first described the effects of goal and context on movement kinematics.

The position of the IREDS over time was sampled by OPTOTRAK at a frequency of 100 Hz, with 0.1 mm accuracy at a distance of 2.5 m. Static reliability for the instrument has been established in this lab (intraclass correlation > .99). The two-dimensional raw data from the OPTOTRAK were converted to three-dimensional coordinates, using a direct linear transformation algorithm. After being collected, the data were stored for off line analysis.

Procedure

During the experiment, the participant sat in front of a table with the dominant hand holding a checker and resting in a start position (i.e., on the table directly in line with the ipsilateral shoulder). The arrangement of the checkers relative to the checkerboard was reversed for the right- and left-handed participants. The participant performed two practice trials and five test trials for each of the four conditions. Only the test trials were kinematically analyzed. The four conditions were operationalized as follows:

1. The one-step condition: The participant put the checker on a designated place on the checkerboard.
2. The two-step condition: The participant brought the checker to the first designated place and jumped over another checker to a second place on the board.
3. The three-step condition: The participant brought the checker to the first place and jumped over two checkers to a third place on the board.
4. The four-step condition: The participant brought the checker to the first place and jumped over three checkers to a fourth place on the board.

In the two- to four-step conditions, the participants were required to actually touch the checkerboard during the between stops.

Data Reduction

The converted OPTOTRAK data were filtered by the Northern Digital Data Analysis Program (DAP), at a low-pass cutoff frequency of 5 Hz using a second-order Butterworth filter with forward and backward passes. On the basis of pilot data, the start and end of movement steps were defined as the first point in time when the hand's velocity along the mediolateral axis exceeded and decreased to 5 mm/sec. The velocity of the hand, instead of vertical displacement, was chosen as criterion because it was found in the pilot study that some participants lowered their wrist after the checker touched the board (endpoint), causing the vertical displacement to continue to change. The mean reaction time of 0.45 sec in this study suggests that no participant experienced delay in initiating their movement. In case of missing data, a linear spline in the DAP was applied to interpolate the obscured data up to 10%. Two trials (1.42% of all data) required interpolation of 10% of the data. Trials with greater than 10% missing data were eliminated. As a result, only two trials (1.42% of the data) were lost.

A custom-written program was used to provide kinematic scores. Only the first movement step (i.e., movement from the start position to the first designated place) was compared across the four conditions, because previous research has suggested that difference in strategy could be inferred from the initial movement segment (Marteniuk et al., 1987). The dependent variables of this study included reaction time, number of movement units, movement time, and peak velocity. Reaction time is the time from the start...
signal (the beginning of data collection) to the start of arm movement. The number of movement units is the number of times the acceleration trace crosses the zero line divided by two. Movement time is the time from the beginning to the end of movement. Peak velocity is the highest instantaneous velocity achieved during the movement.

Additionally, in order to have complementary information on movement strategy, other kinematic variables were explored, including acceleration time, deceleration time, and percentage of movement time to peak velocity.

Data Analysis

The a priori hypotheses were tested using 4 x 4 mixed analysis of variance (ANOVA) with one between factor (sequence—ABCD, BCDA, CDAB, and DABC) and one within factor (order—first, second, third, and fourth presented). The condition effect was embedded in the sequence by order interaction (Rosenthal & Rosnow, 1991). Omnibus $F$s derived from the 4 x 4 mixed ANOVA informed us if there were any statistically significant differences among the four conditions (nondirectional). An alpha level of .05 was used for the mixed ANOVA test.

To further understand the trend of performance, post hoc contrast analysis (i.e., focused ANOVA) was conducted. Contrast analysis was chosen instead of pair-wise comparison because it has greater statistical power. In the pair-wise comparison, the alpha level has to be adjusted for multiple comparisons and thus the statistical power is reduced. In addition, contrast analysis results in an $F$ ratio with numerator of one, which allows the computation of effect size (Rosenthal & Rosnow, 1985). To perform contrast analysis, contrast weights $(\lambda$s) were assigned according to the obtained mean values of the dependent variables in each condition. Greater means would have larger, positive weights, middle ones zero weights, and smaller ones negative weights. The sum of weights has to be zero.

The value of focused $F$ was further used to calculate effect size $r$, which indicates the degree to which the phenomenon under study is manifested (Cohen, 1988). Effect size is free from sample-size influence. According to Cohen, $r$ of .10 indicates a small effect, .30 a moderate effect, and .50 a large effect.

Results

Table 1 shows the results of the 4 x 4 mixed ANOVA. No significant order effect was found in any of the dependent variables, suggesting that the participants’ performances did not systematically become better or worse as the experiment was proceeding. The non-significant condition effect on reaction time failed to reject the first hypothesis ($F [3, 72] = 2.13, p = .1045$). Descriptive statistics shows that the reaction time was longest in the three-step condition and shortest in the four-step condition (Table 2, Figure 1); computation of the effect size from the contrast analysis revealed that this phenomenon was of moderate-to-large magnitude ($r = .45$). The second hypothesis was supported by the significant condition effect on movement units ($F [3, 72] = 4.71, p = .0047$). The three- and four-step conditions had more movement units than the two-step condition, which in turn had more movement units than the one-step condition; the strength of this relationship was large ($r = .60$).

Results did not support the third hypothesis because the condition effect on movement time was not significant ($F [3, 72] = 0.69, p = .5591$). Although movement time was longest in the one-step condition and shortest in the three- and four-step conditions, the strength of this relationship was only small-to-moderate ($r = .28$). Finally, the fourth

<table>
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<th>Source</th>
<th>df</th>
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<th>MS</th>
<th>$F$</th>
<th>$p$</th>
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hypothesis was supported by the significant condition effect on peak velocity ($F[3, 72] = 3.45$, $p = .0210$). Peak velocity was highest in the four-step condition and lowest in the one-step condition, and this relationship was of large magnitude ($r = .53$).

Explorative analyses on other kinematic variables found no significant difference on percentage of movement time to peak velocity (ranging from 37.10% to 38.72%) or deceleration time (ranging from 0.46 to 0.47 sec). Significantly longer acceleration time was found for more simple tasks ($F = 3.11$, $p = .03$, $M = 0.31, 0.30, 0.29, 0.28$ sec for tasks with one to four steps, respectively), suggesting that movements were more preplanned in tasks with fewer steps.

**Table 2. Descriptive Statistics and Contrast Analysis for the Experimental Conditions.**

<table>
<thead>
<tr>
<th>Variables</th>
<th>One-step</th>
<th>Two-step</th>
<th>Three-step</th>
<th>Four-step</th>
<th>Focused</th>
<th>Effect size</th>
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<tbody>
<tr>
<td>Reaction time (sec)</td>
<td>M (SD)</td>
<td>0.45 (.15)</td>
<td>0.44 (.13)</td>
<td>0.47 (.14)</td>
<td>0.42 (.14)</td>
<td>6.14</td>
<td>0.45</td>
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<td>Movement units</td>
<td>M (SD)</td>
<td>1.72 (0.68)</td>
<td>2.14 (0.76)</td>
<td>2.24 (0.78)</td>
<td>2.26 (0.78)</td>
<td>13.86</td>
<td>0.60</td>
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<tr>
<td>Movement time (sec)</td>
<td>M (SD)</td>
<td>0.78 (.21)</td>
<td>0.76 (.17)</td>
<td>0.75 (.15)</td>
<td>0.75 (.17)</td>
<td>2.07</td>
<td>0.28</td>
</tr>
<tr>
<td>Peak velocity (m/sec)</td>
<td>M (SD)</td>
<td>0.64 (0.15)</td>
<td>0.67 (0.15)</td>
<td>0.67 (0.12)</td>
<td>0.68 (0.15)</td>
<td>9.78</td>
<td>0.53</td>
</tr>
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</table>

**Discussion**

As expected for the first hypothesis, no statistically significant difference was found in reaction time among the conditions. In addition, the second hypothesis was supported by the results showing significantly more movement units in the three- and four-step conditions than in the one- and two-step conditions. These results are in line with previous findings by van Donkelaar and Franks (1991a, 1991b), who reported that when the repetitive elbow flexion–extension movement became more complex and their young participants moved at a slower speed, reaction time did not increase significantly, but movement units did. However, the moderate-to-large effect of task complexity on reaction time found in the present study cannot be overlooked. Results of this study suggest that when the elderly participants performed tasks at self-paced speeds, they planned part of the movement in advance and left the rest of movement to be controlled online. The increase of reaction time and movement units from the one- to three-step condition suggests that within three steps, both the preplanning and online control increased in the elderly participants as the checker task became more complex. On the other hand, the shortest reaction time and most movement units in the four-step condition may imply that the elderly participants left most of the movement to be controlled online when the complexity demands exceeded their preplanning capacity.

The third hypothesis that movement time would be longest in the one-step condition compared to the others...
was not supported by the non-significant findings on movement time. The discrepancy between our findings and previous findings by Adam et al. (1993) and Lajoie and Franks (1997) may be attributed to the slight difference in the requirement for participants’ performance. Adam et al. instructed the young participants to slide the stylus smoothly and as quickly as possible toward the target; and Lajoie and Franks asked the young participants to make one smooth movement to each target. In contrast, our study let the elderly participants move at self-paced speeds and movement smoothness was not a requirement. We speculate that movement time in the two- to four-step conditions did not decrease as much as was expected, because our participants were not asked to do the task as fast as possible. In addition, movement with more movement units (i.e., less smooth) tends to also have longer movement time (for online correction; Brooks & Watts, 1988). Because the elderly participants in this study were not constrained to move smoothly, their natural movement showed increased movement units as the task became more complex, and thus their movement time could not be further reduced.

Results of this study support the fourth hypothesis that peak velocity would be lower in the one-step condition than in the others. The results are in line with the findings of Adam et al. (1993) and Lajoie and Franks (1997), who reported higher peak velocity in a two-step movement than in a one-step movement. Although in this study the endpoint of the first step movement was operationally defined as the decrease of the velocity of the hand along the mediolateral axis to 5 mm/sec, the hand’s resultant velocity, which was calculated using data from all three Cartesian coordinates (X, Y, & Z), might still be higher than zero. Therefore, it is possible that in the two- to four-step conditions of this study, the participants glided through the first designated place and went on, instead of completely stopping and then restarting. As it has been reported that peak velocity increases as amplitude of movement (i.e., distance) increases (MacKenzie, Marteniuk, Dugas, Liske, & Eickmeier, 1987), the higher peak velocity in the more complex condition may also be attributed to the longer total distance that the participants had to move. In addition, because peak velocity is regarded as being correlated with the force of movement (Nelson, 1983), it is likely that peak velocity was higher in the more complex condition because more force was embedded in the first movement segment in order to drive the longer subsequent movement sequence.

Complementary information on movement strategy could also be obtained from kinematic variables such as acceleration time, deceleration time, and percentage of movement time to peak velocity. Although there was no significant difference in deceleration time or percentage of movement time to peak velocity among the four conditions, the significantly shorter acceleration time in more complex tasks suggests that shorter time was spent in movement preplanning in tasks with more steps. The results of less preplanned movement in more complex conditions echo the findings mentioned earlier of increased movement units (i.e., more online controlled movement) in more complex tasks. The convergent evidence obtained from movement units and acceleration time strengthens the notion that movement in a complex task tends to be less preplanned and more online controlled than movement in a simple task.

It may be argued that in this study, the effect of task complexity is confounded with the effect of movement stop in the comparison between one-step condition and the others. However, we consider that the general findings on task complexity still hold because the trend of higher peak velocity and more movement units could also be observed from the two- to four-step conditions. Future research may ask participants to either stop on or glide through a target when doing tasks with various numbers of steps in order to disentangle the effect of movement stop from that of task complexity.

Moreover, although the checker task in this study was considered ecologically relevant, it was composed of very basic movements. The findings of this study may or may not be generalized to even more complex tasks that people perform on a regular basis in everyday life. Future work may be expanded to include tasks that are more complex than the one used in this study.

**Conclusion**

This study shows that motor characteristics are influenced by task complexity, supporting occupational therapy’s tradition of analyzing and grading activities along the complexity dimension. A more complex task elicited more forceful and less smooth movement in the elderly participants of this study. Therefore, according to the treatment goal, occupational therapists working with elderly people may manipulate the number of movement steps within a task for a variety of purposes. For example, if the treatment goal is to facilitate the force embedded in movement, therapists could provide tasks with more steps. If the goal is to conserve energy, tasks with multiple steps are rightly broken up into subtasks of fewer steps each. If the goal is focused on movement smoothness, tasks with fewer steps are more appropriate. Finally, results of this study are generally consistent with previous findings from motor control studies that employed contrived, lab-type tasks, suggesting that movement control literature provides helpful references for ther-
apists to ground their activity analyses in research evidence. However, in order to have more direct evidence to verify or guide our practice, replications of this study are needed in other clinical populations. ▲

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References


