THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

DEPARTMENT OF KINESIOLOGY

TASK DIFFICULTY AND THE TIME SCALES OF MOTOR LEARNING

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in Kinesiology
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Abstract

Performance dynamics of learning can be decomposed into a slow time scale of persistent change over trials and sessions and a fast time scale of warm-up that appears at the beginning of a practice session. ***Purpose:*** To investigate the influence of task difficulty on the slow time scale of learning and the fast time scale of warm-up. ***Methods:*** Subjects (N = 24, 18-22 years old) were randomly assigned to groups, that were based on task difficulty, of easy, medium, and hard. The subjects completed a star tracing task for 40 trials per day over 3 consecutive days of practice. ***Results:*** Overall, movement time decreased over trials and days, with the largest movement times in the hard condition and the smallest in the easy condition. In addition, the hard condition had the most errors followed by the medium condition then the easy condition. Warm-up decrement appeared at the beginning of each practice session. Warm-up decrement in the hard condition was smaller than the warm-up in the other two conditions, but there was no difference in the exponent of the fast or slow time scales as a function of task difficulty. ***Conclusion:*** Task difficulty progressively affected the level of performance, but not the fast and slow time scales.

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Acknowledgements

We would like to thank the subjects who volunteered for this study and for their cooperation. We thank graduate student Adam King for helping with the data analysis. Also, we would like to thank Tim Benner for devoting his time and effort into making the equipment and program function properly.

Introduction

There are multiple processes that contribute to the dynamics of performance outcome over practice time. One of these processes is that associated with practice or experience leading to learning and relatively permanent changes in the capability for movement. This process of motor learning produces a state in which there is "an increased capability for moving skillfully in the particular situation" (Schmidt & Lee, 1999).

Practice allows for improvements in performance; however, the amount of change in performance alters as practice continues over time. Initially, the progress in terms of the amount of change is large and rapid; however, as practice continues improvements in performance become smaller. This rule is known as the law of practice (Schmidt & Lee, 1999; Heathcote, Brown & Mewhort, 2000), which includes the association between movement time and the number of practice trials. The power function is generally accepted as the law relating movement time to practice trials (Lane, 1987; A. Newell & Rosenbloom, 1981). However, Heathcote, Brown and Mewhort (2000) found that in many studies an exponential function fits practice data better than a power law (see also Newell, Liu, & Mayer-Kress, 2001).

The function of learning has been investigated in many experiments over 100 years (A. Newell & Rosenbloom, 1981), but none have investigated how task difficulty influences the rate of change of the processes (time scales) that produce the performance dynamics. The performance dynamics of learning can be decomposed into a slow time scale of persistent change (learning) over trials and sessions and a fast time scale of warm-up that occurs at the beginning of a practice session (Stratton, Liu, Hong, Mayer-Kress, & Newell, 2007; Newell, Mayer-Kress, Hong, & Liu, 2009). The purpose of this experiment is to investigate the influence of task difficulty (Holding, 1965) on the slow time scale of learning as well as on the fast time scale of warm-up.

It is well established that there is typically a decrement in performance over the time course between practice sessions and an important process contributing to this is what is known as warm-up decrement (Adams, 1952, 1961). Warm-up refers to performance at the beginning of each practice session in which there is a decrement in performance, and the participants try to achieve a performance level equal or better than their highest performance levels on the previous day of practice (Stratton et al., 2007). This performance decrement is why performers in many tasks warm-up in some way at the beginning of a practice session to in effect remove the warm-up decrement from the performance dynamics. Warm-up decrement can have a significant decrement on performance but it is usually eliminated, in most tasks, after a small amount of practice at the beginning of a practice session.

There are two hypotheses that have been advanced to account for this phenomenon: warm-up decrement as forgetting and warm-up as a loss of set (Schmidt & Lee, 1999). The first explanation is that the warm-up decrement is due to the loss of memory for the skill. The long rest periods allow for this initial forgetting of the skill; nevertheless, as the trials go on, subjects are able to relearn the task. The second explanation states that the loss of skill is due to a temporary loss of body adjustments or states (Schmidt & Lee 1999) that requires task relevant practice to overcome.

While the fast time scale change at the beginning of a practice session is a reflection of warm-up, the slow time scale is dominated by the persistent change in learning (Newell et al., 2009). In other words, the permanent influence of learning is reflected by the gradual change in movement time after each trial of the task. Even though there is warm-up decrement at the beginning of each day of practice, subjects are eventually able to reduce this effect at the beginning of a practice session (Adams, 1952, 1961). After many days of practice, the size of the warm-up effect tends to wane as the persistent improvements in performance reach a plateau, but initial indications are that the warm-up time scale does not change over practice sessions (Newell et al., 2009).

In this study, the participants will have approximately 24 hours of rest between each day of practice. They will receive no practice before starting each practice session; thus, warm-up decrement is expected to be produced at the beginning of each day of practice. In this study, three groups were assigned to a star tracing task (Stratton et al., 2007) that had varying degrees of task difficulty in order to test three hypotheses. First, it was hypothesized that an increase in the level of task difficulty will decrease the rate of the slow time scale of motor learning. Second, it was hypothesized that increasing the level of task difficulty will increase the amount of warm-up as reflected in the fast time scale of the performance dynamics at the beginning of the second and third practice sessions. Finally, it was hypothesized that the level of task difficulty will influence the initial level of the warm-up decrement for each day of practice but not the rate of change of the exponent of warm-up decrement over days (Newell et al., 2009).

Methods

Participants:

The participants in this study were undergraduate student volunteers (N = 24; age 18-22 years) from the State College, Pennsylvania area, and The Pennsylvania State University. Participants were divided equally into one of three groups of task difficulty. The participants were all right-handed and had no experience in the star-tracing task. Each participant completed The Pennsylvania State University's approved Institute Review Board informed consent procedures.

Apparatus:

A Cintiq 21Ux graphics tablet, a stylus, and a Dell laptop were used to run the study and collect data. A star tracing program was used to evaluate movement time and the number of errors. Error was defined as the number of times the participants moved the pen point out of the star pattern being traced.

Experimental Design:

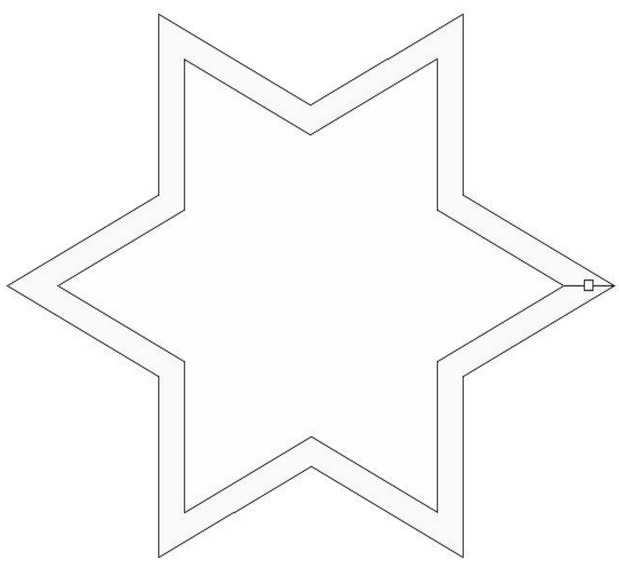

Figure 1. Representation of the star pattern used in the experiment.

Figure 1 depicts the star figure that was used for this study. The star shape was 500 mm long in the middle of the pathway, and the width of the pathway was 4 mm, 7 mm and 10 mm based on level of difficulty: hard, medium, and easy, respectively. Each participant was randomly assigned to one of the difficulty levels. Participants performed 40 trials per day for 3 consecutive days of practice.

Procedures:

Participants were instructed to move the stylus as quickly and accurately as possible within the star pattern. Total movement time and total number of errors were recorded during the task. Moving outside of the star pathway was considered an error.

The location of the stylus on the graphics tablet was indicated by a black dot. To begin a trial, participants placed the black dot in the small square box within the star and stayed in the box until a tone was sounded, which indicated that tracing could begin. Participants traced the star pattern in a counterclockwise motion. Once the participants traced around the star and came back to the square box the trial ended. After completion of each trial a movement time and error score appeared at the bottom of the graphics tablet.

To start the next trial participants were instructed to press the button on the side of the stylus. Participants were able to continue the task at their own pace. When ready, participants placed the black dot back in the square box and followed the same procedure for all 40 trials of each practice session.

Data Analysis:

Movement Time

The main dependent variable of this study was the time it took to complete each trial, which was measured in milliseconds. For the statistical analysis of the movement time data, a task difficulty (3) x day (3) x trial (40) repeated measure ANOVA was used.

Time Scales

The two times scale model (Newell et al., 2009) is represented by the combination of two equations consisting of a fast timescale and a slow time scale.

$$\text{Fast + Slow Time Scale: } V_f(n) = V_{inf} + \alpha_s e^{-\gamma_s n_j} + \alpha_f e^{-\gamma_f (n - n_{j-1})} \quad (1)$$

The individual data were fit to Equation 1, with the goal of minimizing the mean square error difference between the data and model. Seven different parameters were manipulated within the model to derive the best fit. The seven parameters included: V_{inf}, slow α and γ (α_s and γ_s), and fast α_1, α_2, α_3 and γ (α_{f1}, α_{f2}, α_{f3} and γ_f). The first component of the model, V_{inf}, is a fixed point that represents each individual's performance level. The coefficient parameter, α, represents the amount of improvement in performance over a day of practice, while γ represents the growth rate. Slow and fast is used to designate the respective time scales α and γ. The fast time scales has three α components, α_1, α_2, and α_3 to represent the rate of improvement on days 1, 2 and 3, respectively.

The ratio of warm-up relative to V_{inf}, asymptote of performance, was found by taking fast α_1 divided by V_{inf}, α_2 divided by V_{inf}, and α_3 divided by V_{inf}. This was done for each day of practice. To analyze the ratios, a task difficulty (3) x warm-up (3) ANOVA with repeated measures for day was used.

Two subjects were excluded from the time scale analysis because the variability of their movement times did not allow for an adequate fit to the model.

Error

The other dependent variable measured was the amount of error incurred for each trial. An error occurred when participants moved the stylus out of the star pathway. If the participants moved the stylus to the interior or exterior of the star pathway it was considered an error. For the analysis of error a task difficulty (3) x day (3) x trial (40) repeated measure ANOVA was completed.

Results

The primary focus in the analyses was to observe whether there was a change in the performance dynamics of a learning curve due to a change in task difficulty. Both the slow time scale of learning and the fast time scale of adaptation were examined as a function of task difficulty, practice day and trials.

Movement Time

Figure 2 shows the mean task-time for each level of task difficulty as a function of trial and practice days. Overall, for each group there was a decrease in movement time over trials, $F(39, 819) = 10.230$, $p < .01$. There was a significant main effect of day on movement time, $F(2, 42) = 21.196$, $p < .01$, with day 1 having the largest movement time ($M = 11.63$, SD = 1.32), followed by day 2 ($M = 9.81$, SD = 1.03), and then day 3 ($M = 9.23$, SD = .98). The main effect of task difficulty was also significant, $F(2, 21) = 4.871$, $p < .05$. The most difficult condition had the largest mean ($M = 14.91$, SD = 1.91), followed by the medium group ($M = 9.00$, SD = 1.91), and then the easy group ($M = 6.76$, SD = 1.91). The post hoc analysis revealed that there was a significant difference between the hard and medium conditions ($p < .05$) and the hard and easy conditions ($p < .01$), but no significance between the medium and easy groups ($p > .05$). The analysis showed no significant interactions between these three factors. However, the day x difficulty interaction showed a trend toward significance, $F(4, 53) = 2.739$, $p = .07$.

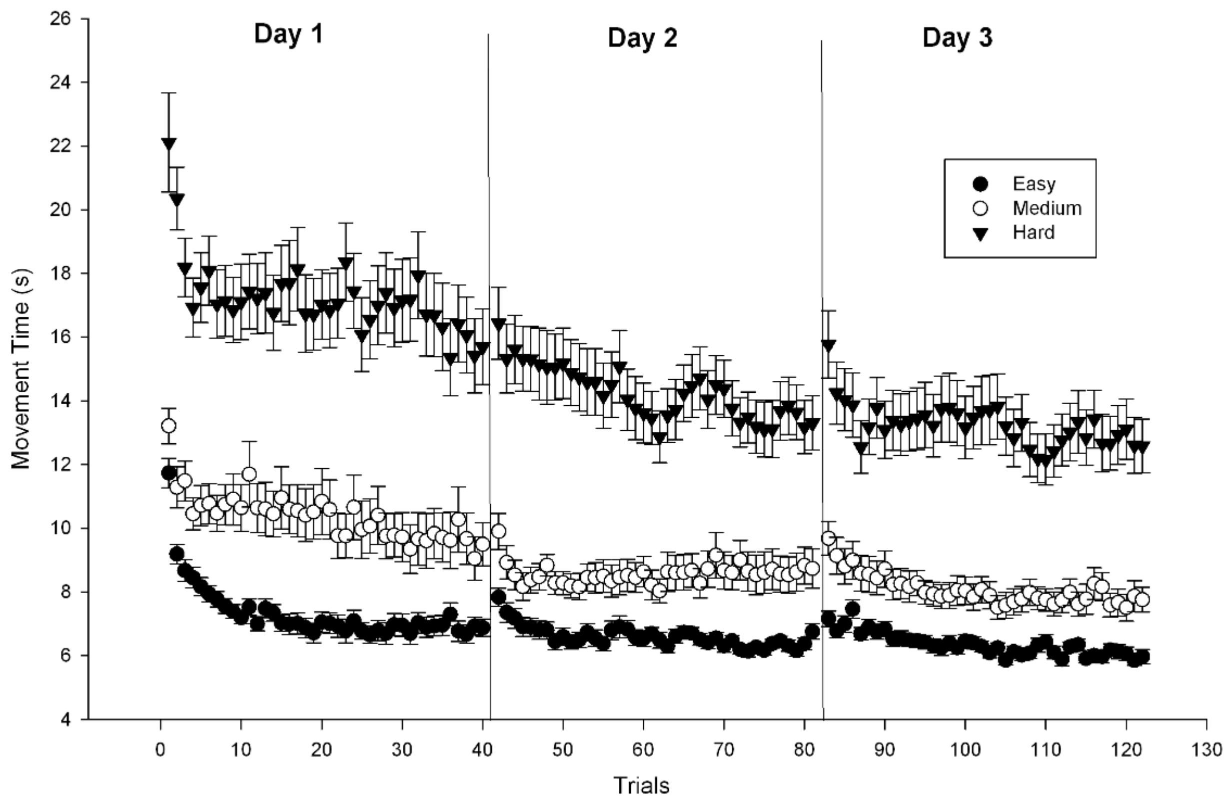

Figure 2. Group-averaged data from all three task difficulty groups over the course of practice.

Time Scales

The effect of warm-up on the fast α parameter of Equation 1 over days was significant, F (2, 38) = 10.349, p < .001. Post hoc analysis showed that there was a significant difference between day 1 (*M* = -.585, SD = .066) and day 2 (*M* = -.272, SD = .042) (p < .01), and day 1 and day 3 (*M* = -.283, SD = .059) (p < .01); however, no significance was found between day 2 and day 3 (p > .05). The effect of task difficulty was significant, F (1, 19) = 4.142, p < .05. The post hoc analysis revealed a difference between the hard (*M* = -.240, SD = .061) and medium (*M* =

-.462, SD = .061) ($p < .05$) and hard and easy (*M* = -.439, SD = .057) ($p < .05$) conditions, but no significance was found between the medium and easy ($p > .05$) conditions.

The effect of task difficulty on V_{inf} and α_s was significant, $F(2, 21) = 5.469$, $p < .05$, and $F(2, 21) = 4.579$, $p < .05$, respectively. There was no significant difference between task difficulty and the other five parameters; γ_s, $F(2, 21) = .708$, $p > .05$, α_{f1}, $F(2, 21) = 1.795$, $p > .05$, α_{f2}, $F(2, 21) = 1.874$, $p > .05$, α_{f3}, $F(2, 21) = .011$, $p > .05$, and γ_f, $F(2, 21) = .350$, $p > .05$. In addition, there was no significant difference between $\alpha_{f1} \times V_{inf}$ and task difficulty, $F(2, 21) = 1.069$, $p > .05$, $\alpha_{f2} \times V_{inf}$ and task difficulty, $F(2, 21) = 1.847$, $p > .05$, and $\alpha_{f3} \times V_{inf}$ and task difficulty, $F(2, 21) = 2.266$, $p > .05$.

Error

The effect of task difficulty on error was significant, $F(2, 21) = 123.358$, $p < .01$, where the largest error was in the hard condition (*M* = 17.75, SD = .835), followed by the medium (*M* = 2.54, SD = .835), and easy (*M* = .95, SD = .835) conditions. The post hoc analysis revealed that there was a significance between the hard and medium groups ($p < .001$) and the hard and easy groups ($p < .001$), but no significance between the medium and easy groups ($p > .05$). Trial and day did not show a significant difference on error, $F(39, 819) = .801$, $p > .05$ and $F(2, 42) = 1.493$, $p > .05$, respectively. There were no significant interactions between these three factors on error.

Discussion

In a study by Snoddy (1935), two growth functions were found to make up the learning curve and performance over time. These two growth functions are the framework of the performance dynamics of learning consisting of a slow time scale of persistent change and a fast time scale of warm-up decrement (Newell et al., 2001). This study investigated these processes of learning, known now as the two time scale model. (Newell et al., 2009). Participants were put into one of three groups designated by task difficulty, and performed 40 trials a day for three days in order to investigate the effects of task difficulty on the time scales of learning.

Overall for each task difficulty group, movement time decreased over days; however, the average movement times were different for each group. Those in the hard condition had the largest movement times followed by those in the medium then the easy conditions. In the study by Stratton et al. (2007), movement times for their two vision conditions, compatible and incompatible, decreased over practice days with those in the compatible condition reaching an asymptote before the last practice session. Furthermore, they considered the incompatible condition to have a higher task difficulty, as such the movement times in this condition were above those of the compatible condition over all practice days.

The hypothesis that the rate of the persistent change of learning would decrease with an increase in task difficulty was not supported. The results showed no effect of task difficulty on the rate of the slow time scale of learning. At this time there are no studies regarding task difficulty and the time scale of motor learning to compare this finding. Nevertheless, Snoddy (1926) found that in various populations and ages of college students and in different types of practice a constant slope was established for the facilitation line, or slow time scale.

Warm-up decrement was found at the beginning of each day of practice (Adams 1952, 1961). Warm-up decreased with days, but the mean initial warm-up decrement on day 2 was slightly smaller than on day 1. Adams (1952) found that warm-up decrement decreased as practice increased for distributed practice, but found no relationship for massed practice, which has been contradicted by other studies.

The results of this study showed that the amount of warm-up decrement was smallest in the hard condition. This finding is opposite to the hypothesis that increasing the level of difficulty will increase the amount of warm-up decrement at the beginning of each practice session. Similarly, Stratton et al. (2007) found that warm-up was not as obvious in the incompatible group as it was in the compatible group. One explanation for this is that the inconsistency of the movement times of the incompatible task masked the trend of improvement in movement time (Stratton et al., 2007). The same can be said for the hard condition of this study, which can be seen by the large standard error bars in Figure 2. Since the effects of task difficulty on the change in performance dynamics have not been studied previously, future research is needed to determine whether this effect on warm-up is general.

Figure 2 shows warm-up decrement between groups based on group averages, and it appears that the hard condition has the largest warm-up decrement. On the contrary, when the individual data are considered, the opposite is apparent; namely, the easy group has the largest warm-up decrement. Averaging data distorts the time scales of the learning curve, and additionally, hides the changes in performance evident in individual data (Heathcote et al., 2000; Newell et al., 2001). Even though there are problems associated with averaging data, it does provide a mechanism for observing general trends; therefore, averaging data will continue (Heathcote et al., 2000).

Since the power law is based on average data, it is potentially flawed and many studies now consider the exponential function a better fit for the learning curve (Heathcote et al., 2000; Newell et al., 2001; Stratton et al., 2007). One of the most referenced papers on motor learning, Snoddy (1926), established that a power law provided the best fit. Yet, Snoddy (1935) started to make a change toward an exponential function rather than a power function. As a result, to analyze the time scales (Newell et al., 2001, 2009), individual data were fitted to an exponential function (Equation 1).

The level of task difficulty influenced the initial level of warm-up decrement for each day of practice but not the rate of change as indexed by the exponent of warm-up decrement over days. As task difficulty increased so did the amount error. Yet, the amount of error over trials and days was essentially constant. Similar results were found in Stratton et al. (2007): the error in the compatible condition was essentially constant, while there was an initial decrease in error followed by no change in error in the incompatible condition. Participants in the incompatible condition had a larger amount of error than the compatible condition over trials. Again the incompatible condition of the study by Stratton et al. (2007) is comparable to the hard condition in this study.

A limitation to this study was that in Equation 1 the rate was held constant while α varied. It would be beneficial to complete an analysis of rate of warm-up on practice. Also, fatigue was an issue, especially for the hard condition. In the future, rest intervals could be included for each condition. Furthermore, there were only 8 subjects in each condition. For any further research into the effects of task difficulty on motor learning, more subjects would provide for a more powerful investigation.

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Appendix:

INFORMED CONSENT FORM FOR BIOMEDICAL RESEARCH
The Pennsylvania State University

ORP OFFICE USE ONLY:
DO NOT REMOVE OR MODIFY
IRB#33508 Doc. #1007
The Pennsylvania State University
Institutional Review Board
Office for Research Protections
Approval Date: 11/15/10 TLK
Expiration Date: 03/16/11 TLK

Title of Investigation: Time Scales in Motor Learning (c)

Principal Investigator: Karl M. Newell, Ph.D.
275 Recreation Building
Penn State University, University Park, PA 16802
814-863-2426

Other Investigators:

Purpose of the study: This research study examines the processes of learning new movements and in particular, the rate of change with which learning occurs.

Procedures to be followed: In this experiment, your task will be to learn a drawing task so that your performance is at the highest level that you can make it in the time available. We are going to study you learning to draw a line on a drawing board over a series of practice trials. Each trial takes about 10 seconds to complete and you will perform with rests for about 30 minutes on each day of practice. There will be 3 days of practice that we would like to schedule consecutively.

Age: Individuals must be 18 years of age or older to participate.

Discomforts and risks: There are no known discomforts and risks in this experiment other than perhaps becoming a little bored toward the end of each practice session.

Benefits to me: There are no direct benefits to you from this study other than being part of a general scientific effort geared to understanding the process of learning.

Potential benefits to society: The researchers hope to provide more information regarding learning processes over time and specific activities; there are many features still to be learned about the process of motor learning.

Time duration of the procedures and study: As we indicate above, the time period of each practice session will be about 30 minutes each day for three consecutive days (Total experimental time is 1 1/2 hours).

Statement of confidentiality: All records associated with your participation in the study will be subject to the usual confidentiality standards applicable to medical records (e.g., such as records maintained by physicians, hospitals, etc.), and in the event of any publication resulting from the research no personally identifiable information will be disclosed. The following may review and copy records related to this research; The Office of Human Research Protections in the U.S.

Dept. of Health and Human Services; The U.S. Food and Drug Administration (FDA); The Penn State University Institutional Review Board; The Penn State University Office for Research Protections.

Right to Ask Questions: Please contact Dr. Karl Newell at 814-863-2426 with questions, complaints or concerns about the research. You can also call this number if you feel this study has harmed you. If you have any questions, concerns, problems about your rights as a research participant or would like to offer input, please contact The Pennsylvania State University's Office for Research Protections (ORP) at (814) 865-1775. The ORP cannot answer questions about research procedures. All questions about research procedures can only be answered by the research team.

Injury Clause: Medical care is available in the event of injury resulting from research but neither financial compensation nor free medical treatment is provided. You are not waiving any rights that you may have against the University for injury resulting from negligence of the University or investigators.

Voluntary participation: Your participation in this study is voluntary, and you may withdraw from this study at any time by notifying the investigator. You may decline to answer specific questions. Refusal to take part in or withdrawing from this study will involve no penalty or loss of benefits you would receive otherwise.

If you agree to take part in this research study and the information outlined above, please sign your name and indicate the date below.

You will be given a copy of this document for your records or future reference.

____

Participant Date

____

Person Obtaining Consent Date

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