Subjective evaluations of the performance proficiency for fluctuating musical sounds using Fluctuation Strength or Roughness

Nozomiko Yasui, Masafumi Kinou and Masanobu Miura

Graduate School of Science and technology, Ryukoku University, 1-5, Yokotani, Oe-cho, Seta, 520-2194 Otsu, Shiga, Japan
n-yasui@mail.ryukoku.ac.jp

The "Fluctuation Strength (FS)" and the "Roughness" were suggested as evaluation indices of hearing sensation concerning fluctuated sounds of low or high frequencies. Past studies have been investigated FS and roughness of modulated pure tones and broad-band noise. However, few studies have been reported concerning FS and roughness of attenuating sounds produced by musical instruments and performance proficiency for them. Therefore, the tremolo played on the mandolin and the open roll played on the snare-drum are employed here as fluctuating musical sounds of low or high frequencies. Introduced here is the FS and roughness as indices for the evaluation of the performance proficiency for tremolo and roll. Specifically, experts of mandolin or snare-drum are asked to play tremolo of various plucking rate (# of plucking per second) and closed roll of various stroking rate (# of stroking per second). An evaluation experiment using the 2AFC method is conducted to evaluate performance proficiency for tremolo and roll. Aesthetic performances of tremolo and roll are described as "smooth, or not fluctuated" by trained players. The amount of physical FS for tremolo and physical roughness for roll are calculated by an original procedure to investigate relations between physical indices and evaluation results.

1 Introduction

In performances using a stringed instrument or a percussion instrument that produce attenuating sounds, although players cannot produce continuous sounds in those musical instrument, they can play quasi-continuous sounds produced by repetition of attenuating sounds. The ways of playing each is called as tremolo or roll. The amounts of acoustic amplitude of tremolo and roll are usually fluctuated in terms of time, so those are said to be fluctuating continuous sounds. Therefore, those are assumed to give us the feeling of fluctuation, which are thought to be concerned with subjective evaluation for performance proficiency. The "Fluctuation Strength (FS)" and the "Roughness" have been suggested as indices for evaluating hearing sensation in fluctuating sounds at low or high frequencies. Past studies have investigated those of modulated pure tones and broad-band noise. However, few have been reported on the FS and the roughness of fluctuating musical sounds produced by musical instruments and their proficiency. In addition, there are no suggestions for indices to correspond to their proficiency. Therefore, the tremolo played on the mandolin and the open roll played on the snare-drum are employed here as fluctuating musical sounds of low or high frequencies. Introduced here is the FS and roughness as indices for the evaluation of the performance proficiency for tremolo and roll. Concretely, physical characteristics of tremolo and roll played by experts are investigated, and an evaluation experiment for the tremolo performance proficiency and that roll.

2 Outline of tremolo and roll

The mandolin is one of the plucked string instruments played using a pick. It has paired metal strings tuned approximately in perfect fifth among sets of paired strings. Each pair consists of two strings tuned in almost the same pitch. Two styles of playing the mandolin using a pick, "picking" and "tremolo", are often used in actual performances. "Picking" means plucking the strings using a pick to produce a duple tone while playing a note, "tremolo" means repeating plucking the string using a pick on a pair of strings[1].

"Roll" is a style of performance of percussion instruments such as snare-drum, timpani, marimba, and so forth[2]. For playing roll, percussion players have to repeat beating single note or notes rapidly. On playing snare drums, two styles of roll are commonly used; "open roll" and "closed roll". On playing open roll, players should produce just two strokes by controlling the bouncing drum stick after stroking the first stroke. Figure 1(a) shows its musical score and an example of real performance corresponding to it. As can be seen in Fig.1 (a), just two strokes are produced alternately among left and right hands. On the other hand, on playing closed rolls, players usually produce more than three strokes on each hand movement and strokes by overlapping strokes among hands. Figure 1 (b) shows its musical score and an example of real performance as an estimated pattern.

(a) Examples of musical score and its actual performance of open roll

(b) Example of musical score and its estimated performance of closed roll

Fig.1 Examples of musical scores denoting (a) open and (b) closed roll

3 Past studies of FS and Roughness

FS is one of evaluation indexes of psychological level, proposed by Fastl *et al*, in relation to hearing sensations concerning modulated sounds with a modulation frequency[3]. FS is elicited by modulated sounds with a modulation frequency of up to about 20 Hz or low frequency. "Roughness" which is elicited by modulated sounds with a modulation frequency of within approximately 20-250 Hz or high frequency, was suggested as the other evaluation index of hearing sensation. According to the finding of past studies, it has been clarified that FS for AM SIN with a modulation frequency within 4-8 Hz is larger than that in the range outside of 4-8 Hz, and the strongest sensation for a fluctuation subjectivity is obtained within 4-8 Hz[3]. It has been clarified that roughness for AM SIN with a modulation frequency approximately 70 Hz is larger than that in the range outside of approximately 70 Hz, and the strongest sensation for a fluctuation subjectivity is obtained within approximately 70 Hz [3]. Past studies concerning feeling of fluctuation in musical performances have been conducted using FS or roughness [4-7]. Fastl measured FS of sinusoidally amplitude modulated uniform masking noise as a function of modulation frequency, modulation depth, and sound pressure level[4]. Rauber *et al*., extracted the physical characteristics of fluctuations that are critical to recognize rhythm patterns in various frequency bands for the current acoustical information using FS[5]. Kurakata *et al*., reported that the pattern of fluctuation of intensity in piano performances is related to FS[6]. Fujisawa *et al*., investigated fluctuation in frequency of the Japanese pressed voice, Dami-Goe, using roughness [7].

4 An investigation into tremolo

4.1 Method on investigation into tremolo

In this study, the plucking rate is focused according to our assumption that plucking rate affects hearing sensation and subjective evaluation for tremolo more strongly than other factors. Though it is thought that the timbre of the tremolo also affects subjective evaluation, it is also thought that common timbre among players is rare because the timbre relates to various individual factors. Therefore, an investigation was conducted without comparing among players in order to exclude inter-player differences. An experiment is conducted to evaluate tremolo performance proficiency at three plucking rates (6, 8, and 9 Hz) played by seven mandolin experts. Aesthetic performances of tremolo are said to be “smooth” or “not fluctuating” by trained players, so the amount of FS for tremolo is originally calculated by extracting a fluctuation component of about 4-8 Hz from acoustic data. The procedure for objectively calculating the amount of FS is designed based on facts reported by past studies[3,4] and our assumption that characteristics of tremolo are somewhat similar to AM SIN of slow speed. Therefore, we hypothesized that “the fluctuation components extracted originally from a tremolo influences the feeling of fluctuation (or an aesthetic evaluation)”. Here, the calculated FS is called “physical FS”, while the FS proposed by Fastl *et al*. is called “psychological FS”. Investigated here is a relation between the physical FS of a tremolo and the player’s proficiency.

4.1.1 Recording experiment

Outline of experiment: The tremolo played by seven mandolin experts were recorded by a microphone in a soundproof room.

Players: Seven mandolin players (P_1-P_7) with over three years experience.

Task: They were asked to play tremolo at three plucking rates, 6, 8, and 9 Hz, for five seconds in a soundproof room. Then, they were instructed to play for longer than thirty-seconds at 90, 120, and 135 bpm (corresponds to 6, 8, and 9 Hz, respectively). Click sounds were presented with the tempo using a dynamic earphone from a metronome to only the left ear of the player because presenting the click sound in both ears would interfere with playing. Tone height of the tremolo was D4 (about 295 Hz), or the open tone for the third pair of strings. Intensity of sound was asked to be constant and to be “*p* (piano)”, based on experts’ comments that they can recognize easily the difference between an aesthetic tremolo and an unaesthetic tremolo when the intensity of sound is relatively small.

Mandolin: M-150 (SUZUKI VIOLIN Co., Ltd.).

Pick: A black 0.635-mm-thick pick made of nylon (YAMAHA) and shaven as to play it easily.

Recording equipment: A metronome (DB-90, Roland Co., Ltd.), a dynamic earphone (ME-L91D, SONY Co., Ltd.), a microphone (NT2-A, RODE Microphones) and a recorder (HD-P2, TEAC Co., Ltd.). Sounds were recorded in 16 bits for each sample at a rate of 48 kHz.

4.1.2 Subjective evaluation experiment

Outline of experiment: An evaluation experiment using the 2AFC method was conducted to evaluate tremolo performance proficiency with listeners in a soundproof room.

Listeners: Six other mandolin players with over a half year of experience.

Stimuli: Twenty-one tremolo performances were presented as the stimulus sound, i.e., three plucking patterns times seven players.

Equipment: An electrostatic earspeaker (SR-303, STAX Ltd.) and an amplifier (SRM-313, STAX Ltd.).

Procedure: For each player, stimuli consisting of two conjunctive performances were presented to listeners. The two tremolo sounds were presented one immediately after the other, and listeners were asked to subjectively select the better one. Stimuli were presented through earspeaker to the listeners. Before the experiment, each listener was allowed to adjust the acoustic level of sound to the level that best enabled him or her to listen to tremolo. As a result, the average level chosen was approximately 62.5 dBA.

4.1.3 Procedure for calculating physical FS

Figure 2 shows the procedure for calculating physical FS. The levels of acoustic power of tremolos ($S_{1,1}, S_{1,2}, S_{1,3}, S_{2,1}, S_{2,2}, S_{2,3}, \ldots S_{7,3}$) were equalized so as to be approximately equal. Tremolos were divided into several waveforms (ID: 1 ~ N) respectively ($f_1(t) \sim f_N(t)$ shown in Fig.2). The wavelength and shift width of each waveform were 1 sec and 0.5 sec, respectively. FFT was performed for all acoustic data converted to absolute values for all sampled data. In calculating physical FS, a band-pass filter for 4-8 Hz was used to cut signals of other regions of the converted data. IFFT was performed for them, and the averages of RMS values of the obtained waveforms were calculated. The physical FS of the tremolo of m Hz performed by player l ($F_{l,\ m\,\mathrm{Hz}}$) was obtained by summing up obtained RMS values over the divided waveforms.

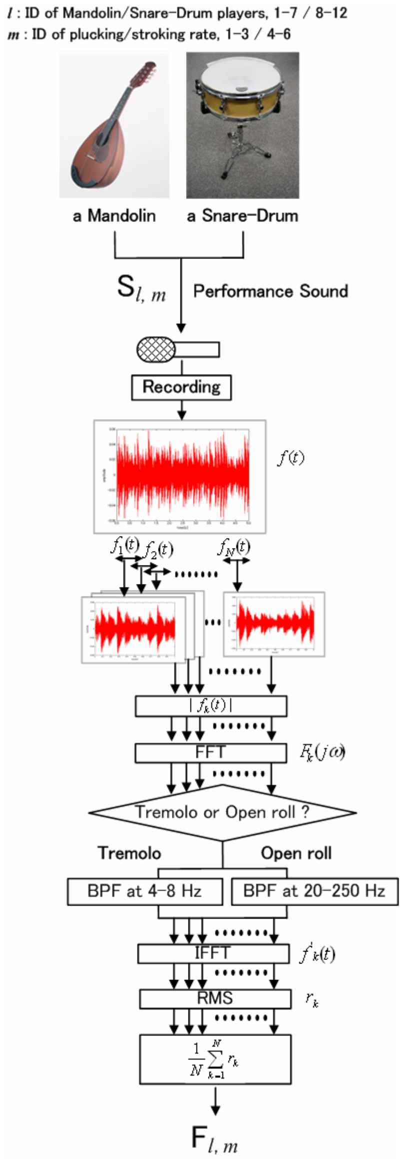


Fig.2 Procedure of calculating physical FS/roughness

4.2 Results on investigation into tremolo

Table 1 shows results of evaluating subjectively the tremolo performance proficiency for each player. As can be seen in Table 1, it is confirmed that tremolos performed at plucking rates of 8 or 9 Hz was evaluated as good. The chi-square test for goodness-of-fit was conducted determine to whether or not the results were significantly affected by plucking rates. It is found that the results were significantly affected by plucking rates of all players ($p < .05$).

Figure 3 shows the amount of physical FS for tremolos performed by each player. As can be seen in Fig. 3, faster rates correspond to smaller amounts of physical FS. However, it is confirmed in some cases that the amount of physical FS is small despite a slow plucking rate (for example, between P_7's 8 Hz and P_2's 6 Hz performance). This is thought to be because of the difference in timbre and/or irregularity of plucking. Though it was pointed out about the influences of FS on the situation of irregularity in the past study [6], it has not been investigated intensively. This should be discussed in the near future.

	Plucking rate		
Player	6Hz	8Hz	9Hz
P_1	4* (11 %)	10* (28 %)	22* (61 %)
P_2	2* (6 %)	18* (50 %)	16* (44 %)
P_3	0* (0 %)	14* (39 %)	22* (61 %)
P_4	5* (14 %)	11* (30 %)	20* (56 %)
P_5	3* (7 %)	14* (39 %)	19* (54 %)
P_6	6* (16 %)	10* (28 %)	20* (56 %)
P_7	3* (7 %)	18* (50 %)	15* (43 %)

The number of cases evaluated as good (%)

* : $p < .05$

Table 1 Results of evaluating subjectively the tremolo performance proficiency performed by each player

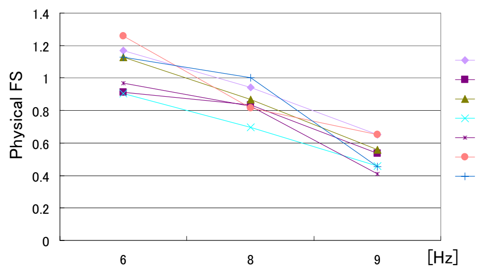


Fig.3 Amount of physical FS for tremolo played by each player calculated by original procedure

5 An investigation into open roll

5.1 Method on investigation into open roll

In this study, the stroking rate is focused according to our assumption that stroking rate affects hearing sensation from open roll and subjective evaluation for open roll more strongly than other factors. Here, an investigation was conducted as shown method in 4.1 because of the reason shown, same in 4.1. Investigated roll performance is the open roll only in this study. Investigated stroking rates are 12, 14, and 16 Hz. Here, the calculated roughness is called "physical roughness", while the FS proposed by Fastl *et al.* is called "psychological roughness". Investigated here is a relation between the physical roughness of an open roll and the player's proficiency.

5.1.1 Recording experiment

Outline of experiment: The open roll played by five snare-drum experts were recorded by a microphone in a soundproof room.

Players: five snare-drum players (P_8-P_{12}) with over four years experience.

Task: They were asked to play open roll at three stroking rates, 12, 14, and 16 Hz, for five seconds in a soundproof room. Then, they were instructed to play for longer than thirty-seconds at 88, 104, and 118 bpm (corresponds to 6, 8, and 9 Hz, respectively). Click sounds were presented as with the way of investigation into tremolo. Intensity of sound was asked to be constant and to be "*mp* (mezzo piano)".

Snare-drum: Sonic Plus II (SONOR Inc.)

Drum stick: Playwood M-15C (made by maple wood).

Recording equipment: Same as shown in 4.1.1.

5.1.2 Subjective evaluation experiment

Outline of experiment: An evaluation experiment using the 2AFC method was conducted to evaluate open roll performance proficiency with listeners in a soundproof room.

Listeners: Five other drum players with over three years of experience.

Stimuli: Fifteen open roll performances were presented as the stimulus sound, i.e., three stroking patterns times five players.

Equipment: Same as shown in 4.1.2.

Procedure: Same as shown in 4.1.2. The average level chosen was approximately 66.7 dBA.

5.1.3 Procedure for calculating physical roughness

Figure 2 also shows the procedure for calculating physical roughness. The levels of acoustic power of open rolls ($S_{8,4}$,$S_{8,5}$,$S_{8,6}$,$S_{9,4}$,$S_{9,5}$,$S_{9,6}$,…$S_{12,6}$) were equalized so as to be approximately equal as shown in 4.1.3. The procedure is same as shown in 4.1.3, except for the range of a band-pass filter. In calculating physical roughness, a band-pass filter for 20-250 Hz was used to cut signals of other regions of the converted data.

5.2 Results on investigation into roll

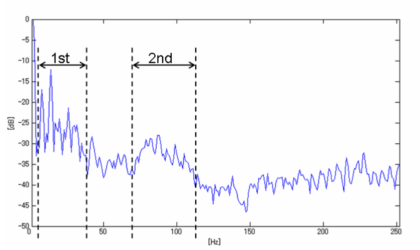
Table 2 shows results of evaluating subjectively the open roll performance proficiency for each player. As can be seen in Table 2, it is confirmed that open rolls performed at stroking rates of 14 or 16 Hz was evaluated as good except P_{11}'s performance. The chi-square test for goodness-of-fit was conducted determine to whether or not the results were significantly affected by stroking rates. It is found that the results were significantly affected by plucking rates of players except P_{11}'s and P_{12}'s performance ($p < .05$).
A strong relation is not found between physical roughness and subjective evaluation for open roll. So, shapes of fluctuating spectrum were investigated to confirm detail information of performed sounds, because procedure of calculating physical roughness in this study dose not obtains detail information in that. Figure 4 shows an example of fluctuating spectrum for open roll performed by P_2. The horizontal axis represents fluctuation frequency, and the ordinate axis represents fluctuating amplitude spectrum. As can be seen in Fig.4, two groups of peaks are confirmed in fluctuating spectrum performed at three stroking rate. First group of peaks are confirmed within 0-40 Hz, whereas second group peaks are confirmed within 70-120 Hz. So, it is thought that first group of peaks concerned with stroking rate. It is confirmed that those groups of peaks existed in fluctuating spectrums played by experts except P_{11}.

	Stroking rate		
Player	12 Hz	14 Hz	16 Hz
P_8	1* (3%)	10* (33%)	19* (64%)
P_9	3* (10%)	9* (30%)	18* (60%)
P_{10}	0* (0%)	14* (47%)	16* (53%)
P_{11}	11 (37%)	8 (26%)	11 (37%)
P_{12}	7 (23%)	11 (37%)	12 (40%)

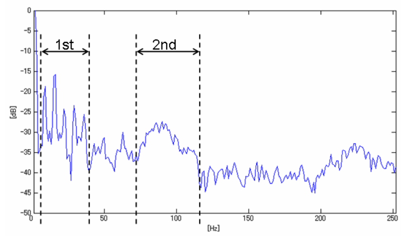
The number of cases evaluated as good (%)

* : $p < .05$

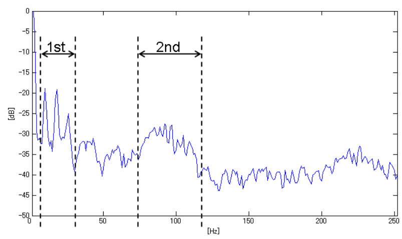
Table 2 Results of evaluating subjectively the open roll performance proficiency performed by each player



(a) 12 Hz



(b) 14 Hz



(c) 16 Hz

Fig.4 Fluctuating spectrum of open roll performed by P_2

6 Discussion

6.1 Tremolo

As can be seen in Table 1 and Fig. 3, highly rated tremolos have a relatively low level of physical FS. Also, physical FS has strong negative correlation with high subjective evaluation (r = -.75(n=21)). Therefore, this shows that physical FS can be used as an evaluation index of the tremolo performance proficiency played on the mandolin. Figure 5 shows the relation between results obtained in this study and psychological FS. The “playable region” is obtained from the results of a questionnaire completed by eight players, who were asked to subjectively describe their own playable region of plucking rate. The answers were confirmed using a metronome. As can be seen in Fig. 5, two strong relations are confirmed among calculated physical FS, subjective evaluation results, and psychological FS. The findings show that "tremolo played on the mandolin is best performed by avoiding higher level of psychological FS under the playable region". However, we think that we should confirm each relation to other plucking rates because only three plucking rates (6, 8 and 9 Hz) were investigated in this study.

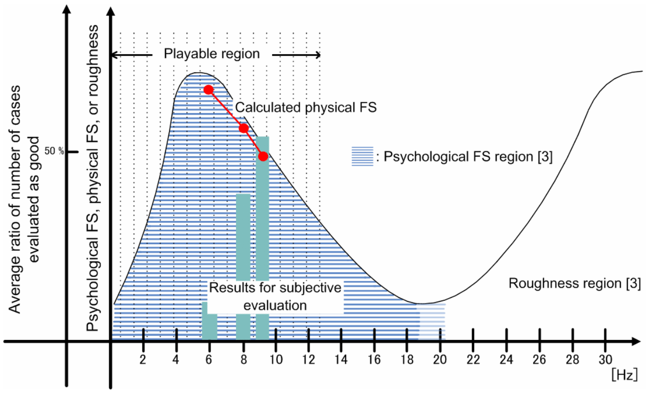


Fig.5 Relation between our results and psychological FS

6.2 Open roll

As can be seen in Table 2, it is confirmed that open rolls evaluated as good has high stroking rate. On the other hand, no relation between physical roughness and subjective evaluation for open roll is found. So, fluctuating spectrums were investigated. As can be seen in Fig.4, it is confirmed that open roll is fluctuating continuous sound elicited roughness, because second group of peaks exist in about 70 Hz of fluctuation frequency that elicits roughness. In addition, investigated here is a relation between fluctuating spectrums and subjective evaluation for open roll according to our assumption that difference between maximum peak in first group of peak and it in second group of peak affects subjective evaluation for it. Figure 6 shows differences between maximum peak in first group of peak and it in second except P_{11}. The horizontal axis represents stroking rate, and the ordinate axis represents difference between maximum peak in first group of peak and it in second. P_{11}'s fluctuating spectrums were excluded, because second group of peak was not found in P_{11}'s fluctuating spectrums. As can be seen in Fig. 6, highly rated open rolls have a relatively small difference between maximum peak in first group of peak and it in second. So, it is thought that open roll evaluated as good is relatively equal in a feeling of fluctuation elicited by stroking performance and a feeling of fluctuation elicited by fast fluctuation.

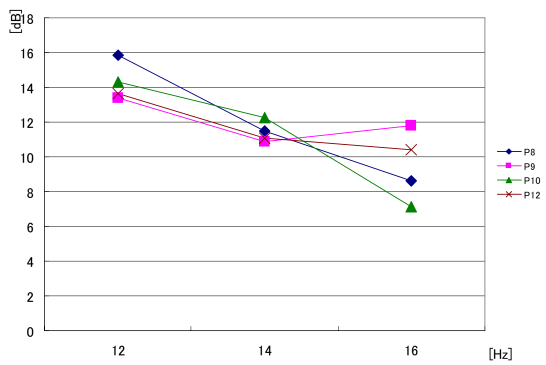


Fig.6 Difference between maximum peak in first and second group of peak

7 Conclusions

This study is a first study that investigates subjective evaluation for performance proficiency based on auditorily standards. Our results show that highly rated tremolo has a relatively low level of physical FS, suggesting that physical FS can be used as an evaluation index for tremolo played on the mandolin.

Though it cannot suggest that physical roughness can be used as an evaluation index for open roll played on the snare-drum, it may have possibility that physical roughness is used as an evaluation index for open roll. In future works, we plan to compare experts with beginners to clarify the relation between physical characteristics of tremolo/open roll and subjective evaluations of tremolo/open roll performance proficiency.

Acknowledgments

The authors are grateful to S. Sugita, M. Yanagida and M. Yamada for their help in giving suggestions and ideas for this study. The authors express sincere thanks to OB/OG and practicing players belong to the Ryukoku University Mandolin Orchestra, T. Nakaji, and professional percussionists, players or listeners, for their help. This study is partly supported by "High-Tech Research Center" Project for Private Universities: matching fund subsidy from MEXT (Ministry of Education, Culture, Sports, Science and Technology), 2006-2011.

References

[1] O. Fujita, "Illustrated the correct way to play Mandolin -for beginners to instructors with concert repertories-", Zen-On Music Company Ltd., (2005, in Japanese)

[2] H. C. Okubo, "Basic Rhythm Method for Snare Drum", ATN (2003, in Japanese)

[3] H. Fastl and E. Zwicker, "Psychoacoustics Facts and Models", pp.247-264, Springer-Verlag (1990).

[4] H. Fastl, "Fluctuation Strength and temporal masking patterns of amplitude-modulated broadband noise", *Hearing Research*, 8, pp.56-69 (1982)

[5] Andreas Rauber, Elias Pampalk and Dieter Merkl, "Using Psycho-Acoustic Models and Self-Organizing Maps to Create a Hierarchical Structuring of Music by Sound Similarity", *Proc. of ISMIR 2002*, Paris, France, October 13-17 (2002)

[6] K. Kurakata, S. Kuwano and S. Namba, "Factors determining the impression of the equality of intensity in piano performance", *Journal of the Acoustical Society of Japan* (E), 14, 6, pp.441-447 (1993)

[7] N. Fujisawa, M. Yamada and I. Nakayama, "Fluctuation in frequency of Japanese pressed voice, Dami-Goe", *Journal of the Acoustical Society of Japan* (E), 21, 6, pp.365-367 (2000)