Original Article

ESTIMATION OF ERROR FOLLOWED BY KNOWLEDGE OF RESULTS IN A MODERATE OR HIGH FREQUENCY ENHANCES MOTOR LEARNING AND MAY AVOID EXTRINSIC FEEDBACK DEPENDENCE

ESTIMATIVA DE ERRO SEGUIDA POR CONHECIMENTO DOS RESULTADOS EM FREQUÊNCIA MODERADA OU ALTA MELHORA A APRENDIZAGEM MOTORA E PODE EVITAR A DEPENDÊNCIA DE FEEDBACK EXTRÍNSECO

Fabiano de Souza Fonseca[1,4], Lucas Savassi Figueiredo[3], Marilya Andrade da Silva Lima[4], Jaime da Silva Souza Maciel[4], Drumond Gilo da Silva[2] and **João Vitor Alves Pereira Fialho[5]**

[1]Federal Rural University of Pernambuco, Recife-PE, Brazil.
[2]Federal University of Pernambuco, Recife-PE, Brazil.
[3]Aeronautical Instruction and Adaptation Centre, Lagoa Santa-MG, Brazil.
[4]University Center Cesmac, Maceió-AL, Brazil.
[5]Pontifical Catholic University of Minas Gerais, Belo Horizonte-MG, Brazil.

RESUMO
O presente estudo teve como objetivo analisar como diferentes esquemas combinando estimativa de erro e frequência relativa de feedback extrínseco afetam a aprendizagem motora. Cinquenta e dois estudantes de graduação (30 homens, 22 mulheres) com idades entre 18 e 35 anos (M = 21,15, DP = 2,97), todos novatos na tarefa, praticaram uma habilidade de produção de força com diferentes combinações entre estimativa de erro e frequência relativa de conhecimento dos resultados. Quatro condições experimentais foram comparadas: 1) nenhuma estimativa de erro com feedback após cada tentativa; 2) nenhuma estimativa de erro com feedback a cada duas tentativas; 3) estimativa de erro seguida de feedback após cada tentativa e 4) estimativa de tentativa após feedback a cada duas tentativas. A análise do erro absoluto da força revelou efeito significante para a frequência de feedback [F(1, 76) = 4.209, p = 0.044, $\eta_p^2 = 0.52$] e estimativa de erro [F(1, 76) = 7.483, p = 0.008, $\eta_p^2 = 0.77$]. A análise do erro constante da força não revelou diferenças significantes para estimativa de erro [F(1, 76) = 2.323, p = 0.132, $\eta_p^2 = 0.37$], mas para a frequência de feedback [F(1, 76) = 8.481, p = 0.005, $\eta_p^2 = 0.83$]. Os resultados mostraram aprendizagem superior dos grupos que combinaram estimativa de erro após receber feedback, independentemente da frequência relativa apresentada. A associação entre estimativa de erro e frequência relativa de feedback extrínseco (alto ou moderado) parece favorecer o desenvolvimento de mecanismos de detecção de erros, evitando os efeitos da dependência de feedback extrínseco e, consequentemente, potencializando o aprendizado.
Palavras-chave: Aprendizagem motora. Feedback. Estimativa de erro. Conhecimento de resultados.

ABSTRACT
The present study aimed to analyze how different schedules combining error estimation and relative frequency of extrinsic feedback affects motor learning. Fifty-two undergraduate students (30 males, 22 females) aged 18 to 35 years old (M = 21.15, SD = 2.97), all novices in the task, practiced a force-production task with different combinations between error estimation and relative frequency of knowledge of results. Four experimental conditions were compared: no error estimation with feedback after every trial; no error estimation with feedback every two trials; error estimation following by feedback after every trial-and-error estimation following feedback every two trials. The absolute force error analysis revealed a significant main effect for both feedback frequency [F(1, 76) = 4.209, p = 0.044, $\eta_p^2 = 0.52$] and error estimation [F(1, 76) = 7.483, p = 0.008, $\eta_p^2 = 0.77$]. The constant force error analysis did not reveal a significant main effect for Error Estimation [F(1, 76) = 2.323, p = 0.132, $\eta_p^2 = 0.37$], but did for Feedback Frequency [F(1, 76) = 8.481, p = 0.005, $\eta_p^2 = 0.83$]. Results showed superior learning of groups that combined error estimation following receiving feedback, regardless of feedback frequency. The association between error estimation and relative frequency of extrinsic feedback (high or moderate) seems to favor the development of error-detection mechanism, thus avoiding the effects of extrinsic feedback dependence, and consequently enhancing learning.
Keywords: Motor learning. Feedback. Error estimation. Knowledge of results.

Introduction

Providing a learner with appropriated feedback about the movement performed during practice is critical for performance and motor learning[1,2]. Feedback can be understood as error information that comprises the discrepancy between the desired and the actual performance[3]. Such information provides the basis for a learner to perform corrections in movements, and consequently, acquire new motor skills and improve performances[4-7]. Traditionally, the studies have investigated the role of feedback on motor learning in form of Knowledge of Results (KR), a type of feedback defined as an error information externally presented about the outcome of performance skill[7]. From a historical perspective, finding the optimal KR schedule and determine its association with other strategies that enhance motor learning has been a challenge for researchers.

Previous studies have extensively investigated the effects of relative frequency of KR on motor skills acquisition. A large body of evidence has shown that providing KR in reduced frequencies (i.e. 33% to 66%) does not impair learning skills such as key-pressing[8], soccer overhead throw[9], dynamometer force-production tasks[10] and anticipatory timing task[11,12] young adults. As a matter of fact, these evidences suggest that reduced KR frequencies may even be more beneficial in comparison to KR after every trial (i.e. relative frequency of 100%)[9,11,13,14,15]. Another strategy that has proven effective to facilitate motor learning is to encourage learners to estimate their errors after trials[16]. This action can be performed regardless of the frequency of KR received, that is, both in trials with KR provision or in trials without KR provision. However, the association between KR frequencies and error estimation still requires further investigation.

According to the Guidance Hypothesis, the KR provided at high frequencies during practice actually guides the learner towards the task goal, which quickly reduces the magnitude and amount of errors, and improves performance immediately[3]. However, frequent exposure to KR promotes negative effects on long-term performance, especially in situations where this information is not available[17]. In other words, the learner performs better during practice when the KR is frequently presented, but the performance is impaired in learning tests when KR is no more provided. Salmoni et al.[3] have argued that frequent KR during practice leads to a dependency on the extrinsic feedback, which prevents the processing of intrinsic sources of information. Consequently, the development of error-detection mechanism can be impaired, and behavioral and neurophysiological studies[18-20] have found evidence supporting the predictions of the Guidance Hypothesis.

The consolidation of error-detection mechanism is considered an essential component for motor skills acquisition[21] and the use of intrinsic feedback seems to be fundamental for this[16]. There is evidence that learning is impaired when intrinsic feedback processing is inhibited throughout the practice. Swinnen[21] conducted three experiments to investigate the effects of interpolation of cognitive recognition activities (secondary task) in the inter-trial interval on learning of a switch task with a temporal demand (primary task) by undergraduate students. The results revealed that the interpolated task in inter-trials interval impaired the learning of the primary task. Additionally, similar negative effects have also been observed when the processing of intrinsic feedback is supposedly inhibited by providing KR immediately after the task execution[18,22,23]. Considering that sensory consequences of movement are processed during inter-trial interval[21], if the learner does not have opportunity to process intrinsic feedback properly in this period the motor learning can be impaired. Therefore, investigate appropriate schedules to combine frequency of providing KR and potentiate ways to use intrinsic feedback has important implications for motor skill acquisition.

Reducing the frequency of KR might be seen as an indirect way of inducing the use of intrinsic feedback. However, by just suppressing KR in some trials does not guarantee that the learner is cognitively engaged in processing of sensory information after the execution. Thus, the use of strategies to directly induce the use of intrinsic feedback should be considered. The subjective estimation of error has been an efficient strategy to directly engage the learner in intrinsic sensory processing and to enhance learning[24-26.] Previous studies that investigated the effect of requiring the participant to estimate response errors immediately after a trial has consistently shown better retention performance when compared to situations in which participants do not error estimate[22,25,26].

Despite the potential benefits of error estimation for motor learning, there is a lack of knowledge in this regard, especially in relation to the effects of associating error estimation and the relative frequency of KR. Although the relative frequency of feedback was a widely investigated topic in literature, to the best of our knowledge, only 2 studies have analyzed the effects of the association between relative frequency of KR and error estimation[24,27]. Guadagnoli et al.[23] conducted a study combining two relative frequency of KR (100% or 20%) and two error estimation conditions (100% or 0%) in a 2x2 factorial design. In this investigation young adults had to learn a simple force-production task, and were asked or not to estimate their errors after trials. Results showed that the association between error estimation following 100% KR enhanced retention performance, while both groups with 20% KR (i.e. with or without error estimation) showed intermediate performance, and the 100% KR without error estimation group performed worse. Similarly, Silva et al.[26] investigated the effects of error estimation on the learning of basketball free shooting movement pattern by 10 to 12 years-old children. These authors also found superior learning for the group combining error estimation and 100% feedback frequency in comparison to 33% feedback frequency groups (i.e. with or without error estimation), which showed better performance than 100% feedback frequency without error estimation group.

Overall, these findings suggest that the association of high frequencies of extrinsic feedback with error estimation seems to be more advantageous to learning even when compared to the groups of low feedback frequencies. An explanatory hypothesis for these results may lay on the that the low relative frequencies of KR used in these studies (i.e. 20% and 33%) minimized the benefit of association with error estimation, impairing proper calibration and consolidation of error-detection mechanism that occurs through the comparison between intrinsic feedback (estimated error) and extrinsic feedback (real error)[21,27]. Thus, for such comparisons to be potentialized one may expect that a minimal amount of extrinsic feedback is required (e.g. moderate relative frequency).

In summary, it has been shown in the relevant literature that estimation of error favors the engagement of the learner in processing intrinsic feedback playing an important role in motor learning. Likewise, a large body of evidence has shown that providing KR in reduced frequencies may be more beneficial than 100% frequency of feedback. Therefore, an appropriate combination between error estimation and frequency of extrinsic feedback may be determinant for the unfolding of error-detection mechanism. So far, it has been shown that only the association of error estimation with high frequencies of extrinsic feedback seems to potentiate learning. However, previous studies only tested the association of error estimation with high and low extrinsic feedback frequencies (100% versus 20% to 33%). We hypothesize that estimation of error combined with moderate and high frequencies can promote superior learning. Therefore, the present study sought to extend this knowledge analyzing the effects of association between stimulated error estimation and higher versus moderate relative frequency of extrinsic feedback on motor learning.

Methods

Sample

Fifty-two undergraduate volunteers (30 Male, 22 Female) aged 18 to 35 years old (M = 21.15, SD = 2.97) with no self-reported sensory or motor dysfunctions participated in the experiment after giving written informed consent. All participants were inexperienced in the task and unaware of the purpose of this study. We employed a convenience sample seeking to represent the population studied in most previous studies in the literature[8,16,22,23]. Similarly to most of these studies, we included as selection criteria that the participants were adults from both sexes with no experience in the task of the study. Additionally, participants reported that they had no experience in sports activities involving manual strength control tasks. For purposes of discussion and generalization of the findings, it was important to select a sample with such characteristics. The experimental protocol and procedures were approved by the local university ethics committee (Protocol nº 1.671.905).

Procedures

A properly calibrated manual dynamometer, model TKK5401 - Takei Scientific Instruments, was used to measure grip force control using the nondominant hand. Participants had their maximum handgrip strength measured during 3 initial trials in order to establish the goal for each participant during the two phases of the experiment. The task involved the application of 50% of the maximum handgrip strength for the duration of 3 sec. with an intertrial interval of approximately 8 sec. The dynamometer display recorded the corresponding value of the handgrip force applied by the fingers on the gauntlet (expressed in kgf) for each trial. The measurement accuracy was 0.5 kgf.

Participants informed the researcher their handedness dominance and performed the task with their nondominant hand in a sitting position without observing the dynamometer display, according to the protocol proposed by Fernandes et al.[28]. A digital stopwatch was also used to control the intervals between trials and the periods before and after receiving feedback.

Experimental Design and Procedures

The experiment was divided into acquisition phase and retention test. Acquisition phase consisted of 40 trials that required the application of 50% of maximum grip force. Retention test was performed 24 hours after the acquisition phase. In this test, participants performed 10 trials with the same specifications as in the acquisition phase, but without extrinsic feedback.

Participants were randomly assigned to four groups (n = 13) with different frequencies of extrinsic feedback and error estimation (intrinsic feedback stimulation): 1) 100% Group (G100), who received extrinsic feedback after each trial; 2) 50% Group (G50), who received extrinsic feedback after every two trials; 3) 100% Group + Error Estimation (G100 + EE), who received extrinsic feedback and was required to estimate its performance after each trial; 4) Group 50% + Error Estimation (G50 + EE), who received extrinsic feedback and was required to estimate its performance after every two trials. Participants in the 50% groups (i.e. G50 and G50 + EE) received feedback on one trial and did not receive feedback for the next trial. Thus, participants in these groups received feedback after trials 1, 3 and 5 but not after trials 2, 4 and 6. This procedure was repeated throughout the acquisition phase.

The error estimation occurred before receiving KR as follows: immediately after execution, the following question was displayed on the computer screen "How do you think your performance was in this trial?”. Five seconds after the question, 5 options were presented for participants to choose: 1) I applied much more force than necessary; 2) I applied a little more force than necessary; 3) I got it right; 4) I applied a little less force than necessary; 5) I applied much less force than necessary. The participants had 5 s to estimate their errors. Thus, the length of the KR-delay interval was approximately 12 s and the post-KR interval was 5 s.

KR was provided in a qualitative and verbal fashion as the difference between task goal and participants' performance. When participants showed errors between 0 and ± 2 kgf, the KR provided was "you got it right". When errors were between ± 2.1 and ± 5 kgf, the KR provided was "you applied a little more force than necessary" or "you applied a little less force than necessary", and when the errors were higher than ± 5 kgf, the KR provided was "you applied much more force than necessary" or "you applied much less force than necessary". This procedure of providing qualitative KR was adapted from the study of Kilduski et al.[29], which employed a similar task to the one used in this study.

Statistical analysis

The main measure of performance accuracy used in this experiment was the Force Error (FE), which is defined as the difference between the target force and the participant's actual force performance. From this error was computed the Absolute Force Error (AFE) and the Constant Force Error (CFE). CFE is defined as the mean of the difference with respect to sign between the target force and the participant's actual force performance over series of trials. It is a measure that represents both the amount and direction of the error, serving as measure of participant's performance bias in undershooting (-) and overshooting (+) the amount of force applied. On the other hand, AFE is defined as the difference between the target force and the participant's actual force performance without respect to sign. It is a measure of the magnitude of the error without regard to the direction of it. Data from both measures were analyzed in 8 blocks of 5 trials in the acquisition phase and 1 block of 10 trials in retention test. As a complementary measure was used the Estimation Accuracy of error for G100+EE and G50+EE groups during the acquisition phase. EA is defined as the mean of the percentage of correct matches between the participant's estimated range of error and actual range of error. Thus, the trial was considered correct in the cases which participant's declared range of force error (e.g. little less force) was considered equivalent to the range of force error presented (e.g. error between -2 and -5 kgf). EA is a measure that aims to evaluate whether the procedure of asking subjects to estimate their performance improved the accuracy of the estimate during practice, and consequently, would substantiate the possible positive effects on learning. Because EA is based on the percent of matches and follows a binomial distribution the arcsine squared root transformation was used to analyze this variable as recommended by Howell[30].

Normality and homogeneity of the dependent variables were verified by the tests of Shapiro Wilks and Levene, respectively. For the inferential analysis, the average performance in the blocks of trials was considered. A two-way ANOVA with repeated measures was conducted in the acquisition phase. It was also conducted a between-subjects Factorial ANOVA to better understand the effects of the two independent variables (i.e. KR Frequency and Error Estimation) in the retentions test. When necessary the Tukey post hoc test was used to identify the differences. Significance was established at $p<0.05$. All analyses were performed using Statistica software version 13 (StatSoft, Tulsa, USA).

Results

Figure 1 shows AFE measures computed across trial blocks for the acquisition phase and the retention test. In acquisition phase, the two-way ANOVA analysis showed no significant effect for groups [$F(3, 76) = 0.349$, $p = 0.789$, $\eta_p^2 = 0.115$] and no interaction [$F(21, 532) = 0.842$, $p = 0.667$, $\eta_p^2 = 0.677$]. However, the analysis revealed a significant main effect for blocks [$F(7, 532) = 43.219$, $p = 0.005$, $\eta_p^2 = 1.000$]. The post hoc test indicated that performance increased from the first block to the other blocks of trials ($p = 0.005$).

The Factorial ANOVA also revealed a significant main effect for both KR Frequency [$F(1, 76) = 4.209$, $p = 0.044$, $\eta_p^2 = 0.52$] and Error Estimation [$F(1, 76) = 7.483$, $p = 0.008$, $\eta_p^2 = 0.77$], indicating that groups with lower KR frequency and with error estimation had a better performance. No significant effect was found for the interaction between the two factors [$F(1, 76) = 0.013$, $p = 0.910$, $\eta_p^2 = 0.05$].

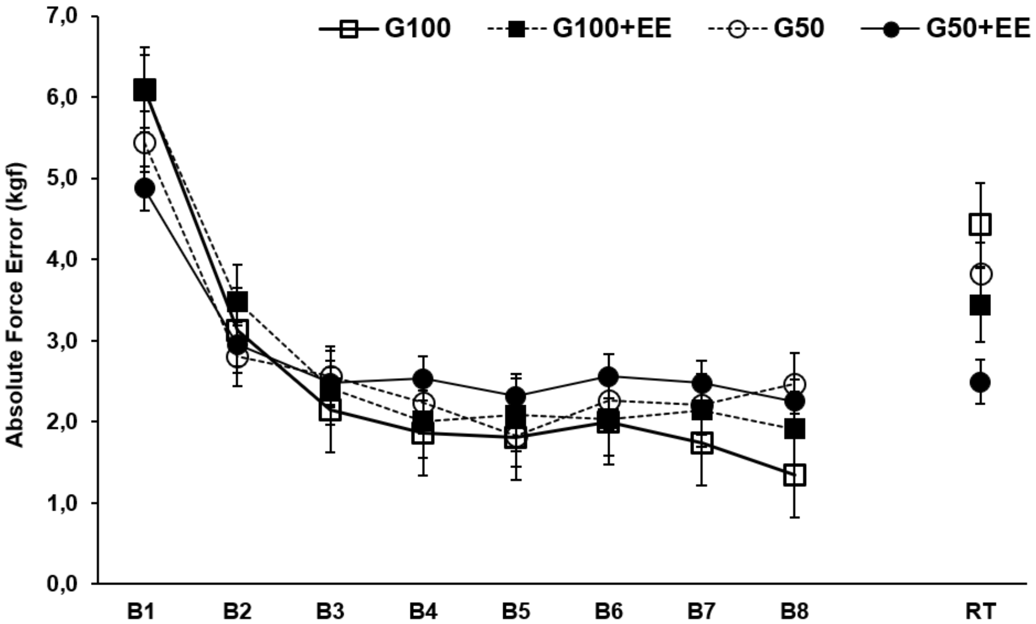

Figure 1. Mean AFE (Kgf) of G100, G50, G100+EE and G50+EE across blocks (5 trials) for the acquisition phase (B1-B8) and retention test (RT).
Note: The error bar denotes standard error (SE) across participants
Source: Authors

Figure 2 shows constant force error (CFE) during the acquisition phase and the retention test. In acquisition phase, the two-way ANOVA analysis showed no significant effect of groups [$F(3, 76) = 1.592$, $p = 0.198$, $\eta_p^2 = 0.403$] and no interaction [$F(21, 532) = 0.758$, $p = 0.770$, $\eta_p^2 = 0.617$]. However, the main effect of blocks was significant [$F(7, 532) = 10.358$, $p = 0.005$, $\eta_p^2 = 1.000$]. The post hoc test indicated higher errors on first block compared to all other trial blocks ($p = 0.005$). The Factorial ANOVA did not reveal a significant main effect for Error Estimation [$F(1, 76) = 2.323$, $p = 0.132$, $\eta_p^2 = 0.37$], but did for KR Frequency [$F(1, 76) = 8.481$, $p = 0.005$, $\eta_p^2 = 0.83$] indicating that groups with lower KR frequency had a better performance. The interaction between the two factors was also significant [$F(1, 76) = 5.146$, $p = 0.026$, $\eta_p^2 = 0.55$].

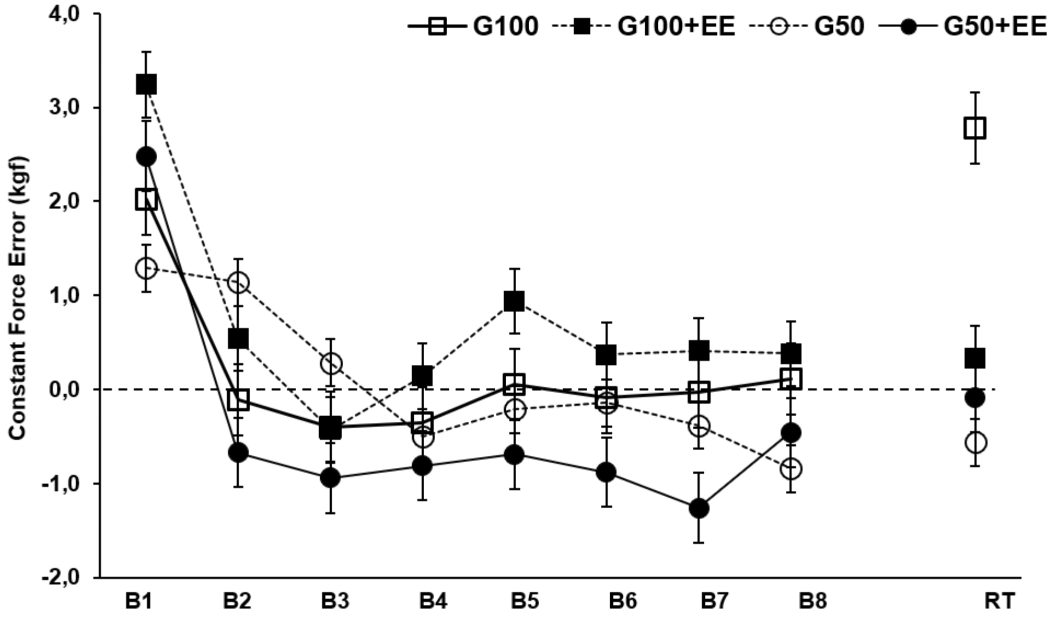

Figure 2. Mean CFE (Kgf) of G100, G50, G100+EE and G50+EE across trial blocks for the acquisition phase (B1-B8) and retention test (RT).
Note: The error bar denotes standard error (SE) across participants
Source: Authors

Simple main effects analyses on conditions with no error estimation revealed that the 50% KR condition (M = 0.50 kgf) produced less CFE than the 100% KR condition (M = 2.80 kgf). However, simple main effects analyses on the error estimation conditions did not reveal statistical significance. Taken together, the analysis indicates that when participants did not estimate errors during acquisition performance, a lower KR frequency enhanced retention performance. When participants did estimate errors, however, KR frequency did not improve performance on retention.

Simple main effects analyses on conditions with 100% KR frequency revealed that the error estimation condition (M = 0.35 kgf) produced less CFE than the no error estimation condition (M = 2.80 kgf). However, simple main effects analyses on the 50% KR frequency conditions did not reveal statistical significance. Altogether, these results indicate that when participants received KR after every trial during acquisition performance, error estimation enhanced retention performance. However, when participants received KR every other trial, error estimation had minimal or no effect on retention performance.

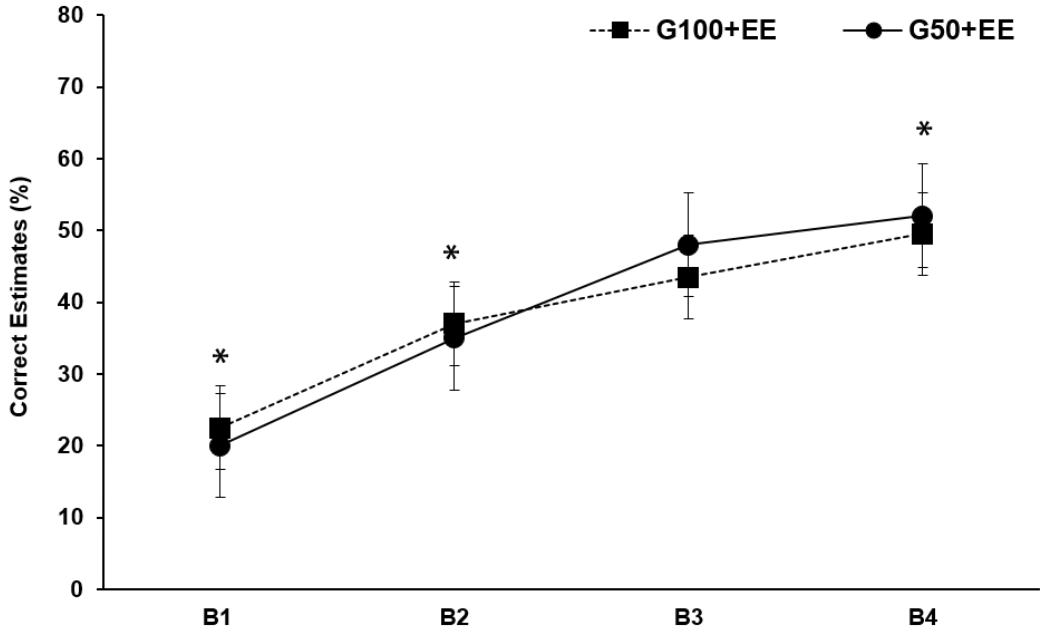

Figure 3. Mean percentage of correct estimates of G100+EE and G50+EE across blocks (10 trials) during acquisition phase (B1-B4).

Note: The error bar denotes standard error (SE) across participants. *Main effect of blocks: the percentage of correct estimates was higher in B4 than in B1 and B2

Source: Authors

Figure 3 shows the mean percentage of correct estimates by G100+EE and G50+EE during the acquisition phase. Analysis indicated a significant main effect of blocks [F(3, 114) = 19.251 $p < 0.001$, $\eta_p^2 = 0.9$]. Post hoc comparisons revealed that the accuracy of the error estimate of the G100+EE and G50+EE groups improved significantly from the second block of the acquisition phase ($p < 0.004$), with the percentage of correct estimates higher in B4 compared to B1 and B2.

Discussion

This study aimed to analyze the effects of associating error estimation with different KR frequencies in motor skill acquisition. Participants were asked to either estimate or not estimate their response produced error before KR was presented under presentations conditions of 100% or 50% frequencies. It was hypothesized that the association between error estimation with moderate and high frequencies of KR could promote superior learning. The results of this experiment supported our hypothesis showing that groups in the conditions with error estimation outperformed the other groups, regardless the frequency of KR presentation. Our study also revealed a systematic and significant difference between the conditions under different KR frequency presentation. Results showed that participants in the conditions with intermediate KR frequency performed better in the retention test than the 100% KR condition. These results are in line with the results found in the literature and provide further support to our hypothesis.

According to the Guidance Hypothesis, a KR dependency was expected in the 100% KR without error estimation condition. This happens because learners would rely much on the always-available extrinsic information, thus inhibiting the processing of the available intrinsic information[3]. That is, when realizing that KR is available every trial, and that this information is simple to use and reliable, the learner modulates his performance from the KR, leaving other sensory information in the background. This may lead to rapid improvements in performance, but when extrinsic information is withdrawn, these learners may have difficulties in maintaining the same level of performance in skill retention[8,10,31,32].

The dependency effects generated by the 100% KR frequency, however, decreased when KR was associated with a strategy to encourage learners to estimate their own errors. In the retention test, the lower error presented by the 100% KR with error estimation condition in relation to the 100% KR without error estimation supports our hypothesis and previous studies[23,26]. A plausible explanation is that the learners were stimulated to perform mental operations to elaborate hypotheses about their own performance based on the intrinsic feedback[21]. After elaborating the hypotheses regarding their performance, learners received KR and were then able to confront their error estimation with the actual performance. The repetition of this operation allowed them to refine their error-detection mechanism, as indicated by the analysis of error estimation throughout the acquisition phase, in which improvements are reported with the course of practice (Fig. 3). In fact, the development and consolidation of the error-detection mechanism is considered fundamental for learning, especially in situations in which KR is not available[3,16]. In these situations, learners must base its performance exclusively on intrinsic sources of information[3]. Thus, it is reasonable to assume that the strategy of requesting subjective error estimation proved to be an efficient way to minimize the effects of extrinsic feedback dependence brought by high frequencies of extrinsic feedback (e.g. 100% KR).

In the present study, we also found that the reduced KR condition associated with the error estimation strategy (i.e. G50+EE) was beneficial for retention performance. This result differs from previous studies in which reduced frequencies with subjective error estimation showed intermediate performances in relation to 100% KR and 100% KR with error estimation strategies conditions. In Guadagnoli et al.[23] and Silva et al.[26] studies, the reduced frequencies of feedback were 20% and 33%, respectively. These frequencies are lower than the reduced frequency used in the present study, which might be the factor that allowed learners in this condition a superior skill retention. Another aspect that may justify the novelty of our findings, specifically in relation to the study by Silva et al.[26], is that their study was conducted with children aged 10 to 12 years. There is evidence that unlike adults, children's learning seems to benefit when high frequencies of extrinsic feedback are provided[33]. To the best of our knowledge, this is the first study to demonstrate learning benefits by the combination of error estimation and moderate frequency of KR specifically in adults.

In the 50% KR with error estimation condition, participants were able to use KR in half of the trials to compare with the desired motor response, leading to a strengthening of error-detection mechanism[34]. However, in the other half of trials participants did not receive KR nor verbally declared their error estimate. This, by itself, does not mean that these individuals did not engage in spontaneous subjective-estimation procedures on trials without KR, even though there was no need to verbally state the result. Besides, the results of error estimation throughout the acquisition phase showed that the 50% + EE condition led to an improvement estimation accuracy as the 100%+EE condition did (Fig. 3). This indicates that rather than primarily relying on the intrinsic feedback in order to test the hypothesis regarding their performance, these individuals possibly maintained intrinsic references of the movement outcomes for longer periods in memory, since they already knew that KR would be provided in the subsequent trial, allowing them to access the quality of their estimate. Carrying out these subjective-estimation procedures and maintaining movement references for longer times in memory comes as a cognitively expensive task, and this additional cognitive effort has previously been understood as a critical factor in motor learning[27,35].

To justify the difference between the results of the reduced KR frequencies with error estimation obtained in the present study and in the two studies mentioned above[23,26], we speculate that the amount of extrinsic feedback in these studies may not have been enough for learners to develop intrinsic feedback use. Low KR frequencies such as 20% and 33% means a greater spacing between trials with KR and may have minimized or retarded the development of their error-detection mechanism. Without the reference provided by extrinsic feedback, it is possible that individuals with reduced KR frequencies have spent much of the practice without being able to test their assumptions about the quality of their motor outcome. This fact may have inhibited the obtainment of the benefits from error estimation process in trials without KR, hindering the learning process. Our results, however, indicate that receiving KR in half of the trials seems to have been enough to allow learners a better development in their error-detection mechanism, as reported by the improvements in error estimates throughout acquisition phase.

The present study contributes towards understanding the role of error estimation in the acquisition of motor skills. Specifically, this article contributes to the expansion of knowledge by verifying that the association of error estimation with intermediate frequencies of KR also favors motor learning by young adults, which had not yet been demonstrated in previous studies. However, this study has some limitations, such as such as the composition of the sample exclusively by adults. Another limitation is the use of a very simple laboratory task. These limitations make it difficult to generalize the results found. In this sense, future investigations are warranted to investigate whether the benefits of the association between KR and error estimation found in the present study also apply to different populations and in the learning of more complex tasks, such as sports tasks.

Conclusion

In summary, the results of study support that learners who were stimulated to estimate their errors before receiving extrinsic feedback (high or moderate frequencies) showed a stronger representation of this skill. These results are attributed to a higher quality of processing intrinsic feedback induced by error estimation, which comes from the engagement in subjective-estimation procedure. This subjective-estimation procedure was enhanced by the need to verbalize an estimate of performance before receiving KR. In addition, it has been shown that even with moderate KR frequencies it is possible to obtain the benefits of externally stimulated error estimation. Such benefits, when applied to reduced feedback protocols seem to be related to the amount of extrinsic feedback available to make comparisons with the estimates made. An interesting question is to whether the performance benefits obtained in this situation are result of the interaction between intermediated KR frequency and error estimation or one of the variables separately. Such proposition, however, has not been tested yet, and remains as a suggestion for future investigations. As practical implications from the findings of this study, we propose that teachers and coaches encourage learners to estimate their errors during motor skills acquisition, as a way to stimulate intrinsic feedback processing and consequently favor motor learning.

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ORCID number:
Fabiano de Souza Fonseca: https://orcid.org/0000-0002-9461-8797
Lucas Savassi Figueiredo: https://orcid.org/0000-0001-5853-4978
Marilya Andrade da Silva Lima: https://orcid.org/0000-0002-7422-3915
Jaime da Silva Souza Maciel: https://orcid.org/0000-0001-8929-5068
Drumond Gilo da Silva: https://orcid.org/0000-0002-1920-3137
João Vitor Alves Pereira Fialho: https://orcid.org/0000-0001-8084-0998

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Correspondence address: Fabiano de Souza Fonseca, Rua Conselheiro José Bezerra 226, Farol. Maceió-AL, Brasil CEP 57055-130 Email: fabiano.fonseca@ufrpe.br