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Article

Perceptual and Motor Skills
2019, Vol. 126(1) 157–179
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DOI: 10.1177/0031512518807341
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Self-Controlled Feedback and Learner Impulsivity in Sequential Motor Learning

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Abstract

Many studies have attributed self-controlled feedback benefits associated with motor learning to learners' greater information processing during practice. However, individual learner characteristics like their impulsivity can also influence how people engage cognitively during learning. We investigated possible dissociations between the types of interaction in self-controlled knowledge of results (KR) and learner impulsivity levels in learning a sequential motor task. Ninety volunteers responded to the self-restraint section of the Barkley deficits in executive functioning scale, and those 60 participants with the highest ($n = 30$) and lowest ($n = 30$) impulsivity scores practiced a motor task involving sequential pressing of four keys in predetermined absolute and relative times. We further divided participants into four experimental groups by assigning the high- and low-impulsivity groups to two forms of KR—self-controlled absolute and yoked. Study results showed no interaction effect between impulsivity and self-controlled KR, and, contrary to expectation, self-controlled KR did not benefit learning, independently of impulsivity. However, low-impulsivity participants performed better than high-impulsivity participants on the absolute dimension of the transfer task, while high-impulsivity learners were better at the relative

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dimension. Cognitive characteristics of automatic and reflexive processing were expressed by the strategies used to direct attention to relative and absolute task dimensions, respectively. Low-impulsivity learners switched their attention to both dimensions at the end of practice, while high-impulsivity learners did not switch their attention or directed it only to the relative dimension at the end of the practice. These results suggest that the cognitive styles of high- and low-impulsive learners differentially favor learning distinct dimensions of a motor task, regardless of self-controlled KR.

Keywords

impulsivity, knowledge of results, cognitive styles, automatic processing, reflexive processing

Introduction

A fundamental inquiry topic in motor learning research is the understanding of which practice factors favor the acquisition of motor skills. Feedback related to knowledge of results (KR) is a central factor in this literature. KR refers to guiding feedback regarding the learner's success with respect to the desired learning goal (Schmidt & Wrisberg, 2008). A number of studies have addressed the particular benefits of providing learners self-control over KR (Carter, Rathwell, & Ste-Marie, 2016; Chiviacowsky & Lessa, 2017; Chiviacowsky & Wulf, 2002, 2005; Patterson & Carter, 2010).

Two main hypotheses have been used to account for the learning benefits of self-controlled KR. The motivational hypothesis proposes that self-controlled KR satisfies the basic psychological needs of autonomy and competence. The learner acquires control over one aspect of practice, filling the basic psychological need for autonomy (Sanli, Patterson, Bray, & Lee, 2013) and he or she can seek KR after perceived good trials, resulting in enhanced perceived competence and self-efficacy (Chiviacowsky, 2014). The increased sense of autonomy and competence results in enhanced intrinsic motivation (Figueiredo, Ugrinowitsch, Freire, Shea, & Benda, 2018). On the other hand, the informational hypothesis asserts that self-controlled KR benefits are primarily obtained by a well-developed mechanism of error detection and movement correction (Carter & Patterson, 2012). Performance estimation seems to be a critical process underlying motor learning when self-controlled KR is available. In this explanation, the learner's choice to request or not request KR after a learning trial permits the learner to maximize the KR's informational value by comparing key incidents of perceived and actual outcome differences that optimize the encoding process and strengthen accurate memory representation. Informational hypothesis rather than motivational hypothesis seems to be critical for explaining why self-controlled KR optimizes motor learning (Carter, Carlsen, & Ste-Marie, 2014; Chiviacowsky & Wulf, 2005). If the informational value of KR is a key factor in self-controlled KR benefits, some new questions are raised by analyzing individual learner differences in information processing.

Information processing can be (a) explicit, reflecting conscious, controlled, and deliberative processes, made mostly in a serial manner, or (b) implicit, reflecting unconscious, automatic, and intuitive processes, allowing parallel processing (Kahneman, 2011; Richetin & Richardson, 2008). These two different systems of information processing are intrinsically related to impulsive behavior. Strack and Deutsch (2004) proposed the existence of reflective and impulsive systems that activate the same behavioral schemata and operate in parallel. In the reflective system, behavior is understood as a consequence of the decision process in which sensory, conceptual and motor elements are connected through semantic relations to which a truth value is assigned. In the impulsive system, behavior results from an automatic spreading activation in an associative network, in which relations are associative links between elements and are formed according to the principles of contiguity and similarity.

Individuals more prone to impulsive processing differ in several cognitive and motor aspects from those less prone to impulsive processing. An epitome or extreme version of the impulsive processing style is seen among learners with highly impulsive behavior, and researchers have attended to learning styles of these learners. Leshem (2015), for example, observed that high-impulsive, relative to low-impulsive, individuals had greater difficulty inhibiting responses and resolving cognitive conflicts when the cognitive load was high. Increased automatic processing observed in high- versus low-impulsive individuals has also been shown to produce differences in motor performance (Lage et al., 2011; Lage, Malloy-Diniz, Neves, Moraes, & Corrêa, 2012; Lemke et al., 2005). While impulsivity is commonly viewed as counterproductive (Gomes et al., 2017; Stanford et al., 2009), increased automatic processing of high-impulsive performers has been found to be functional, if not advantageous, in some specific contexts, especially when conditions demand high temporal or spatial motor execution (Lage et al., 2012).

The informational value of KR may differ when KR interacts with either increased impulsive or controlled learner processing styles and varied task demands. Impulsive processing is fast, requires little cognitive effort, and has a low threshold for handling incoming information (Richetin & Richardson, 2008; Strack & Deutsch, 2004). In contrast, controlled processing requires and utilizes high cognitive capacity (Richetin & Richardson, 2008; Strack & Deutsch, 2004). The learner's option to ask for KR or not demands a greater allocation of cognitive resources to several simultaneous tasks, possibly raising what Janelle, Kim, and Singer (1995) defined as a deeper level of information processing in motor task learning. Thus, it is reasonable to think of extremes created by the interaction between types of KR (externally or self-controlled) and levels of impulsivity. At one extreme, the interaction between a low level of impulsivity and self-controlled KR presents an optimal condition for the explicit learner's involvement in the KR request decision after good or poor trials, as it allows the learner to maximize the informational value of the KR received. In the other extreme, a high level of impulsivity in association with an externally controlled KR produces a different but still optimal condition for a given learner's information processing, since the externally controlled KR demands minimal cognitive effort and helps the impulsive learner to avoid the need to resolve cognitive conflicts associated with the need to decide whether or when to request KR. Two other possible interactions in the middle of the continuum should produce suboptimal conditions: (a) a high level of impulsivity in association to self-controlled KR and (b) a low level of impulsivity in association to externally controlled KR.

Some expectations about the interaction between low impulsivity and self-controlled KR can be conjectured. An effective KR request strategy is to request KR after poor trials in the early phase of practice and to gradually switch to requesting KR after good trials. Initially, KR after poor trials helps calibrate performance toward the task goal and, later, KR after good trials helps reinforce behavior (Carter et al., 2014). This dynamic strategy initially requires deliberative and effortful cognitive processes that are apt to be better managed by low-impulsive learners. Throughout practice, cognitive resources are then modified toward more automatic processes, decreasing the task's working memory demand (Krause, Agethen, & Zobe, 2017). The same dynamic strategy might be expected when a motor task requires learning more than one spatial or temporal goal. For example, sequential tasks can require both the learning of relative times between movement components (movement pattern) and the parallel learning of an absolute time (movement parameterization), characterized by the sum of each component time (Apolinário-Souza et al., 2016; Lage et al., 2017; Lai, Shea, Wulf, & Wright, 2000; Lelis-Torres, Ugrinowitsch, Apolinario-Souza, Benda, & Lage, 2017; Shea, Lai, Wright, Immink, & Black, 2001). In this type of motor task, the use of a dynamic information processing strategy is essential to learning. The learner needs to handle information about both the movement pattern and movement parameterization to achieve the two goals required.

Other expectations regarding the interaction between a high level of learner impulsivity and an externally controlled KR can be raised. Such cognitive resources as working memory and inhibitory control are recruited when automatism, instinct, or intuition are insufficient to cope with an ongoing task demand (Diamond, 2013; Kluwe-Schiavon, Viola, Sanvicente-Vieira, Malloy-Diniz, & Grassi-Oliveira, 2017). High-impulsive individuals receiving an externally controlled KR are not expected to recruit higher order cognition to effectively monitor their performance as they do not need to decide if they need KR or not. This type of interaction between the learner's information processing style and control over KR would not be expected to favor a dynamic strategy to learn more than one task goal. Rather, it favors an economic cognitive style better suited to high-impulsive learners, because it does not require careful monitoring in relation to when to request or not request KR. A high-impulsive learner might struggle to manage the dynamic strategy in order to handle additional information about movement pattern and movement parameterization. The greatest advantages of impulsive processing are its fast speed and minimal requirements for cognitive effort (Strack & Deutsch, 2004), but in some contexts, this style is dysfunctional or suboptimal (Lage et al., 2012).

An efficient and flexible goal-directed behavior requires an adaptive cognitive control system for selecting contextually relevant information and for organizing and optimizing processing pathways (Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004). We hypothesized an interaction such that low learner impulsivity and self-controlled KR would result in better learning than other interactions between these variables, as this interaction should favor the use of a dynamic strategy for deciding whether to receive KR after good and poor trials; this interaction should best manage handling information about both task goals. Longer information processing times (PTs) between trials should also be found for participants in this condition. On the other hand, the interaction between high impulsivity and an externally controlled KR should favor better learning, compared with the interaction between high impulsivity and self-controlled KR, as the former interaction produces an optimal condition of information processing for high-impulsive individuals. Considering these hypotheses, we aimed to identify the effects of the learner impulsivity level in learning a sequential motor skill under conditions of external or self-controlled KR.

Method

Participants

This study included right-handed undergraduate Brazilian students, of both sexes, aged 18-35 years, naïve with regard to the motor learning task. They were recruited from an university in Belo Horizonte, Brazil. We first classified the impulsivity level of 90 participants (38 men, 52 women; *M* age $= 23.2$, *SD* $= 3.5$ years) with regard to their impulsivity level. We then selected a subset of 60 participants with high- or low-impulsivity levels (30 of each) to complete the whole experiment (24 men, 36 women; *M* age $= 23.3$, *SD* $= 3.7$ years) in a procedure to be described later. All participants had normal or corrected-to-normal vision and signed written informed consent after receiving a full explanation about the study. To assure a right-hand laterality preference, all participants had to reach a minimum laterality quotient of 80 points on the Edinburgh handedness inventory (Oldfield, 1971).

The sample size was defined considering studies that used motor tasks similar to the one used in this study (Apolinário-Souza et al., 2016; Chiviacowsky &

Wulf, 2002; Kaefer, Chiviacowsky, Meira, & Tani, 2014; Lage et al., 2007, 2017; Meira, Fairbrother, & Perez, 2015). The mean sample size used in these studies was 12.5 participants. To accommodate a 20% drop out rate (Hudson & Darthuy, 2009), we required 15 participants in each group. To minimize the probability of the high- and low-impulsive groups having statistically similar impulsivity scores, we adopted the method used by Lage et al. (2012) by which we included in the study's final sample only the participants that achieved the 33.3% highest and lowest impulsivity scores, excluding the participants with intermediate scores (33.3%). Thus, considering that in our study two low-impulsive and two high-impulsive groups were required, the application of the questionnaire to 90 participants was necessary, since 30 (33.3%) were excluded from the final sample after the impulsivity level assessment.

Impulsivity Assessment

We used the adapted and validated Brazilian Portuguese version of the Barkley Deficits in Executive Functioning Scale (BDEFS; Godoy et al., 2015) to assess the volunteers' impulsivity level. The long form version of the BDEFS is a self-report instrument composed of 89 items separated into five subscales assessing specific domains of executive functions in daily life: self-management of time (Items 1–21), self-organization or problem-solving (Items 22–45), self-restraint (Items 46–64), self-motivation (Items 65–76), and self-regulation of emotion (Items 77–89; Barkley, 2011). We considered only the participants' self-restraint subscale score in our impulsivity analysis, since inhibitory control dysfunction mainly explains the impulsive phenotype (Barkley, 2001), and this subscale is composed of 19 items evaluating possible inhibitory control dysfunction. Participants had to analyze each item, considering their own behavior, and classify themselves according to a 4-point Likert scale: *never or rarely* (1), *sometimes* (2), *often* (3), and *very often* (4). The score on the self-restraint section ranges from 19-76 points, where higher scores indicate impulsive behavior related to poor inhibitory control. The results of psychometric analyses by Godoy et al. (2015) validated the BDEFS adaptation to Brazilian Portuguese for healthy Brazilians aged 18-55 years. The correlation between the original and the translated scales was considered high, not only for the total score (Rho $= 0.97$ $p = .01$) but also for the self-restraint subscale (Rho $= 0.77$, $p = .01$). In addition, the scale's internal consistency was considered adequate to the total score ($\alpha = 0.96$) and to the self-restraint subscale score ($\alpha = 0.88$). To test the validity of the Brazilian version of the BDEFS, Godoy et al. (2015) compared this version to other scales that assess other constructs that are substantially related to executive functions, like impulsivity. As expected, there were high correlations between the total score of the Barratt impulsiveness scale and the total score of the Brazilian version of the BDEFS (Rho $= 0.65$, $p < .001$) and the self-restraint subscale score (Rho $= 0.63$, $p < .001$).

Task and Apparatus

A laptop and a numeric keypad were placed on a standard table inside the lab room (see Figure 1(a)), and a specific researcher-designed software program was used to control the experimental task and register the times between pressing the keys (see later for a description of the motor task). Participants were asked to sit on a chair and adjust the position of the numeric keypad to comfortably use it with their right hand.

For the motor learning task, participants were asked to sequentially press four keys (2, 8, 6, and 4) on the numeric keypad, using the index finger of the right hand. The relative criteria segment ratios and the total criterion movement time were presented on the laptop screen before each trial. The relative criteria segment ratios were 22.2% (Key 2–8), 44.4% (Key 8–6), and 33.3% (Key 6–4). The absolute timing criterion was 900 milliseconds (Figure 1(b)). The KR, when

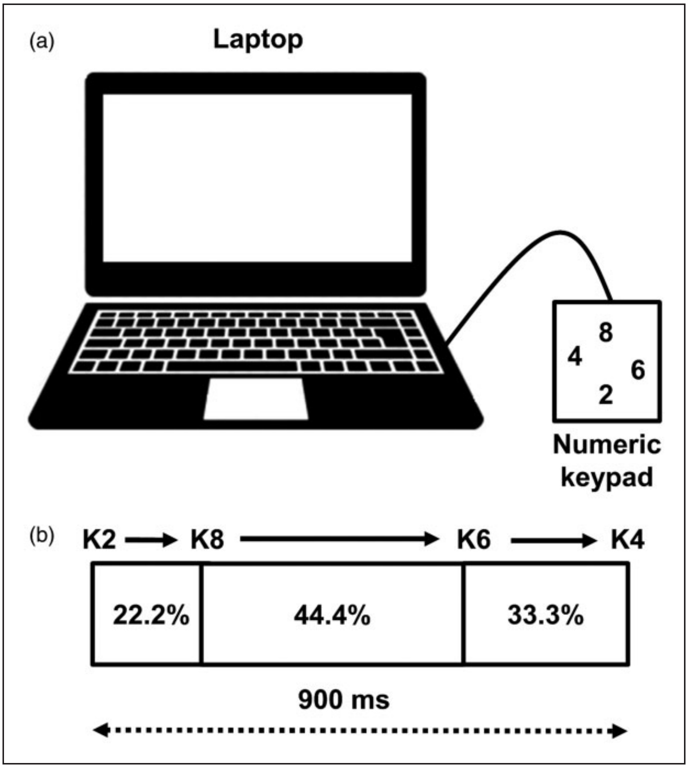

Figure 1. Motor task. (a) Apparatus used to perform the motor task. (b) The sequence of keys typed (K2, K8, K6, and K4), the relative criteria segment ratios between keys (22.2%, 44.4%, and 33.3%) and the total criterion movement time (900 ms).

presented, included the relative segment ratios performed for each segment and the total movement time, as well as the relative timing error (RE), composed of the sum of the segment ratios errors.

Experimental Design and Procedure

After 90 participants responded to the self-restraint section of the BDEFS, their scores were ranked in a descending order. Participants with the 30 highest and the 30 lowest scores were selected to complete the remaining experimental procedures from within high- and low-impulsive participant groups, respectively. The middle scoring participants were excluded from further research activity. High- and low-impulsive participants were further assigned to self-controlled and yoked KR groups, creating four experimental groups of 15 participants each: self-controlled-low impulsive (Self-LI), yoked-low impulsive (Yoked-LI), self-controlled-high impulsive (Self-HI), and yoked-high impulsive (Yoked-HI). The assignment to the self or yoked groups and the counterbalancing of the groups followed the criteria score on the self-restraint survey, sex and age, respectively, and in that order.

Participants next returned to the lab for two consecutive days to perform the motor learning task. We provided them detailed instructions about the task execution, goals, and information displayed on the laptop screen. The volunteers were instructed to be as accurate as possible in both the relative and total time criteria. Self-controlled KR participants (Self-HI and Self-LI groups) were informed that they could request KR up to five seconds after the end of a trial if they considered it necessary by pressing the space bar twice. Yoked participants (Yoked-HI and Yoked-LI groups) only received KR after the same trials on which their paired self-controlled KR participants had requested KR; yoked participants were informed that they would receive KR randomly after some trials during practice. All volunteers performed 120 trials during the acquisition phase. The minimum interval between trials was six seconds and, after this time, the participants could start the next trial whenever they wanted. We applied an adapted questionnaire from Chiviacowsky and Wulf (2002) at three points—after the first, second, and last thirds of the acquisition trials—in order to obtain information about the learners' attention directed to each of the task goals throughout practice and to verify the self-controlled KR learners' KR request strategies. After approximately 24 hours from the end of the acquisition phase, participants performed the retention test, consisting of 12 trials in the same configuration as practiced during the acquisition phase. Finally, immediately after the retention test, participants performed the transfer test, completing 12 trials with a new total criterion movement time of 1300 milliseconds. No KR was provided after any trials of the retention and transfer tests. Two different learning tests were conducted aiming to access two distinct motor learning characteristics, persistence and adaptability. The retention test is better associated to persistence, while the transfer test better accesses the learners' adaptability.

Statistical Analyses

The absolute timing error (AE) and RE were used as proficiency scores on absolute and relative task dimensions, respectively. The AE referred to the difference between the total absolute movement time performed by the participant and the total criterion movement time in each trial and was computed as follows:

$$AE = |MT - \text{total criterion movement time}|$$

The RE was computed as the sum of the differences between the criterion segment ratio and the ratio performed by the volunteer for each segment with the following formula:

$$\begin{aligned} RE &= |R1 - 22.2| + |R2 - 44.4| + |R3 - 33.3|, \quad \text{where R1, R2, and R3} \\ &= (\text{the actual movement time of segment or total movement time}) \times 100 \end{aligned}$$

The processing time (PT) was used to measure the time volunteers spent processing the intrinsic or extrinsic feedback and mentally organizing themselves to execute a new trial; PT was represented by the time interval between the end of a trial (pressing the K4) and the beginning of the next trial (pressing the K2).

As the Kolmogorov–Smirnov Test revealed that AE, RE, and PT had a normal distribution, the data were organized as means (*M*s) and standard deviations (*SD*s) for descriptive analyses. We conducted a one-way analysis of variance (ANOVA) to compare impulsivity levels between the four groups to assure that there were different levels of impulsivity among participants with high and low impulsivity. We used a three-way ANOVA with repeated measures on the blocks factor (two Feedback Types × two Impulsivity Levels × 10 Blocks of 12 Trials Each) for AE and RE measures on the acquisition phase. We conducted two-way ANOVAs (two Feedback Types × two Impulsivity Levels) for AE and RE measures on the retention and transfer tests. We conducted three-way ANOVA with repeated measures on the blocks factor to analyze PT during each third of the acquisition phase (two Feedback Types × two Impulsivity Levels × three Blocks of 40 Trials Each). We used Duncan tests for post hoc analyses when necessary. We used chi-squared tests to compare the frequency of KR requests in the self-controlled groups and the direction of attention to task goals throughout practice. The Bonferroni correction was used for multiple comparisons of the direction of attention to task goals throughout practice. We set the level of statistical significance at 5% for all statistical tests. The eta squared (η^2) was used as a measure of effect size, as it assesses the proportion of the total variation in the dependent variable that is due to the independent variable manipulation, ranging from 0 (*explains none of the variance*) to 1 (*explains all of the variance*; Richardson, 2011).

Results

Impulsivity Level

As expected, an one-way ANOVA confirmed a significant statistical difference between high- and low-impulsivity groups, $F(1, 56) = 57.97$, $p = .001$, $\eta^2 = 0.76$, and post hoc analysis indicated that groups Self-LI ($M = 27.8$; $SD = 3.49$) and Yoked-LI ($M = 28.8$; $SD = 2.86$) each had a lower impulsivity score than groups Self-HI ($M = 43.2$; $SD = 5.89$; $p < .001$) and Yoked-HI ($M = 42.6$; $SD = 4.32$; $p < .001$), respectively.

Absolute Dimension Analyses

Acquisition phase. We present descriptive analyses of the AE data during acquisition in Figure 2. The inferential analysis detected a significant main effect for learning blocks, $F(9, 504) = 11.97$, $p < .001$, $\eta^2 = 0.17$, and post hoc analysis indicated that first block errors were significantly greater compared with the other blocks ($p < .02$). The inferential analysis did not detect a significant main effect for feedback type, $F(1, 56) = 0.05$, $p = .83$, $\eta^2 = 0.001$, or impulsivity level, $F(1, 56) = 1.39$, $p = .24$, $\eta^2 = 0.02$, and there was no significant interaction between these variables, $F(1, 56) = 0.13$, $p = .29$, $\eta^2 = 0.02$.

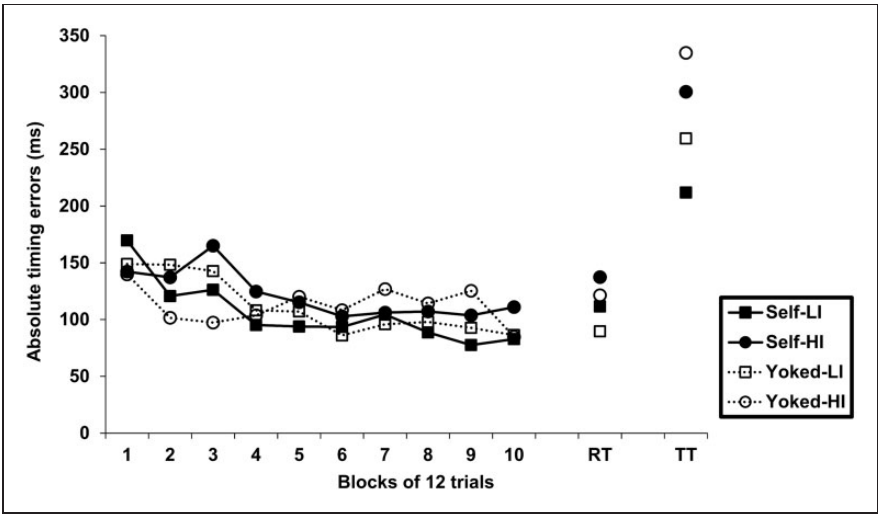

Figure 2. Absolute timing errors (AE) during acquisition (Blocks 1–10), RT, and TT. Significant main effect of blocks was found on acquisition, and main effect of impulsivity level on transfer test ($p < .05$). RT = retention test; TT = transfer test; LI = low impulsive; HI = high impulsive.

Retention and transfer tests. Descriptive analyses of AE data during later testing are also presented in Figure 2. The inferential analysis detected a significant main effect related to impulsivity level, $F(1, 28) = 4.19$, $p = .05$, $\eta^2 = 0.13$, on transfer test. Post hoc analysis indicated that low-impulsivity participants made smaller numbers of errors compared with high-impulsivity participants ($p = .05$). No other main effects or interaction effects were found for the transfer test ($p > .05$). On retention test, the inferential analysis did not detect a significant main effect for feedback type, $F(1, 28) = 1.11$, $p = .30$, $\eta^2 = .04$, or impulsivity level, $F(1, 28) = 2.62$, $p = .12$, $\eta^2 = 0.08$, or any significant interaction between feedback type and impulsivity level, $F(1, 28) = 0.02$, $p = .87$, $\eta^2 = 0.001$.

Relative Dimension Analyses

Acquisition phase. Descriptive analyses for RE data during acquisition are presented in Figure 3. The inferential analysis detected a significant main effect for learning blocks, $F(9, 504) = 33.92$, $p < .001$, $\eta^2 = 0.38$, and post hoc analysis indicated that first block errors were significantly larger compared with errors in other blocks ($p < .001$). The inferential analysis did not detect a significant main effect for feedback type, $F(1, 56) = 0.06$, $p = .8$, $\eta^2 = 0.001$, or impulsivity

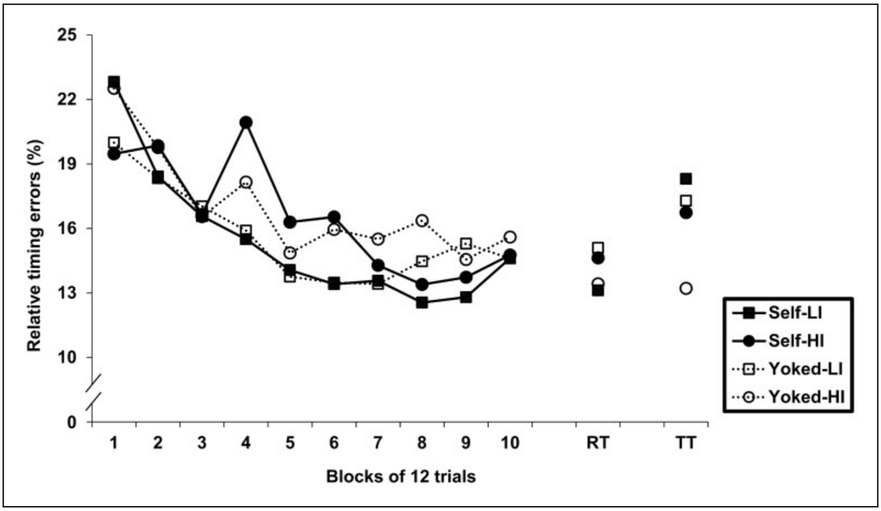

Figure 3. Relative timing errors (AE) during acquisition (Blocks 1–10), RT, and TT. Significant main effect of blocks was found on acquisition, and main effects of feedback type and impulsivity level were found on transfer test ($p < .05$). RT = retention test; TT = transfer test; LI = low impulsive; HI = high impulsive.

level, $F(1, 56) = 3.07$, $p = .08$, $\eta^2 = 0.05$, nor was there any significant interaction between feedback type and impulsivity level, $F(1, 56) = 0.003$, $p = .97$, $\eta^2 = 0.001$.

Retention and transfer tests. Descriptive statistics for RE data during later testing are also presented in Figure 3. The inferential analysis detected significant main effects related to feedback type, $F(1, 28) = 4.46$, $p = .04$, $\eta^2 = 0.14$, and impulsivity level, $F(1, 28) = 7.92$, $p = .008$, $\eta^2 = 0.22$, on transfer test. Post hoc analysis revealed that yoked groups had smaller RE compared with the self-controlled groups ($p = .04$), and high-impulsivity participants had smaller errors compared with low-impulsivity participants ($p = .01$). No impulsivity level by feedback type interaction was found, $F(1, 28) = 1.36$, $p = .25$, $\eta^2 = 0.05$. On retention test, the inferential analysis did not detect a significant main effect for feedback type, $F(1, 28) = 0.16$, $p = .69$, $\eta^2 = 0.001$, impulsivity level, $F(1, 28) = 0.01$, $p = .90$, $\eta^2 = 0.001$, or any interaction between feedback type and impulsivity level, $F(1, 28) = 2.78$, $p = .11$, $\eta^2 = 0.09$.

KR Request Frequency

Descriptive analyses are presented in Figure 4. Chi-squared test revealed a significant difference between groups on the first block ($\chi^2 = 8.11$, $df = 1$, $p = .001$), second block ($\chi^2 = 5.14$, $df = 1$, $p = .02$), and on the total of the 120 trials

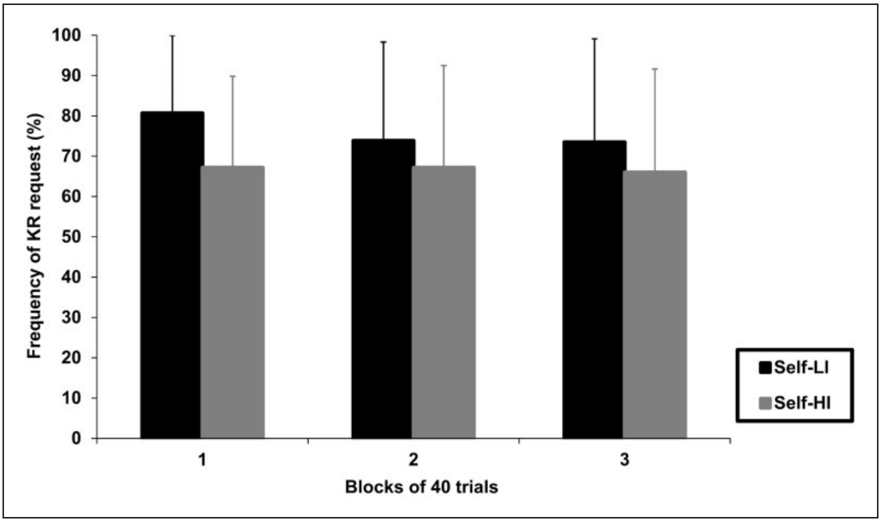

Figure 4. Frequency of KR requests in the self-controlled groups throughout practice. Significant differences between group were found on the first two blocks and in total of trials ($p < .05$). KR = knowledge of results; LI = low impulsive; HI = high impulsive.

($\chi^2 = 13.92$, $df = 1$, $p = .001$), with a greater KR request from the Self-LI group compared with the Self-HI group. No significant difference between groups on the last block was found ($\chi^2 = 2.18$, $df = 1$, $p = .14$).

Processing Time

Descriptive analyses of PT data are presented in Figure 5. The inferential analysis detected significant main effects of feedback type, $F(1, 56) = 12.55$, $p < .001$, $\eta^2 = 0.18$, and blocks, $F(2, 112) = 30.55$, $p < .001$, $\eta^2 = 0.35$. Post hoc analysis indicated a greater PT for self-controlled participant groups compared with yoked groups ($p < .001$), and PT decreased from the first block to the second and third blocks ($p = .001$) and from the second to the third block ($p = .03$). No other significant main effect or interactions were found ($p > .05$).

Questionnaire Analyses

Regarding the KR strategy selected by the self-controlled groups, Self-LI group participants reported preferring to request KR after good trials or equally after good and bad trials. On the other hand, Self-HI group participants mostly

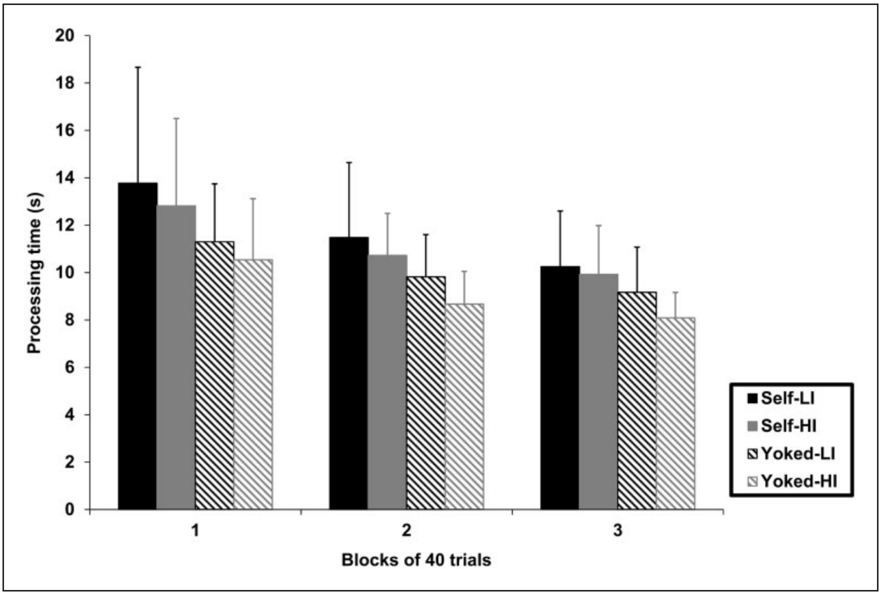

Figure 5. Processing time during the acquisition. Significant main effects of feedback type and blocks were found ($p < .05$). LI = low impulsive; HI = high impulsive.

preferred to request KR after good trials through the entire acquisition phase (see Table 1).

In relation to strategy for switching the direction of attention (see Table 1), on the last third of the trials, groups Self-LI ($\chi^2 = 10.8$, $df = 2$, $p = .004$) and Yoked-LI ($\chi^2 = 7.6$, $df = 2$, $p = .01$) switched their direction of attention by equally prioritizing both dimensions of the task, but on the first and second thirds of

Table 1. Questionnaire and Responses of the Participants of the Self-Controlled and Yoked Groups for Each Third of the Acquisition Phase.

	Self-LI			Self-HI		
	40t / 80t / 120t (NR)			40t / 80t / 120t (NR)		
Self-controlled group						
1. When or why did you ask for feedback?						
(a) Mostly after you thought you had a good trial.	6	9	4	8	8	8
(b) Mostly after you thought you had a bad trial.	0	0	2	0	1	0
(c) When you were in doubt.	3	1	2	2	2	2
(d) After good or bad trials equally.	4	4	6	3	3	3
(e) Randomly.	1	0	0	0	0	0
(f) None of the previous ones.	1	1	1	2	1	2
2. To which task dimension did you direct your attention?						
(a) Absolute time dimension.	0	3	2	0	0	1
(b) Relative time dimension.	6	4	2	7	8	10
(c) In both dimensions equally.	9	8	11	8	7	4
	Yoked-LI			Yoked-HI		
	40t / 80t / 120t (NR)			40t / 80t / 120t (NR)		
Yoked group						
2. To which task dimension did you direct your attention?						
(a) Absolute time dimension.	0	0	2	0	0	1
(b) Relative time dimension.	8	8	3	10	9	6
(c) In both dimensions equally.	7	7	10	5	6	8

Note. LI = low impulsive; HI = high impulsive; t = trial when the questionnaire was answered; NR = number of responses.

acquisition, their attention was directed to the relative dimension or equally to both dimensions. On the other hand, the Self-HI group ($\chi^2 = 8.4$, $df = 2$, $p = .01$), on the last third of the trials, switched the direction of their attention, prioritizing the relative dimension of the task; but, on the first and second thirds of acquisition, they directed their attention to the relative dimension or equally to both dimensions. No change of the direction of attention was found for the Yoked-HI group ($p > .05$) throughout the acquisition phase. For the multiple comparisons after the Bonferroni correction, a difference with a p value equal to or less than .01 was considered significant.

Discussion

This study investigated possible dissociations between types of interactions between self-controlled KR and learner levels of impulsivity in motor learning. Analysis of our two main dependent measures, absolute and relative errors, did not support our hypothesis that an interaction between a low level of impulsivity and self-controlled KR would yield optimal learning compared with other interactions. We found no significant association between this interaction of self-controlled KR and low impulsivity on our dependent measures in the acquisition phase, on the retention test, or on the transfer test. When analyzed separately, KR conditions and levels of impulsivity were associated with some interesting and sometimes unexpected results. Yoked groups performed better than self-controlled groups on the transfer test for relative errors; and an analysis of the effect of impulsivity showed a dissociation between the level of impulsivity and the dimension of the learning task such that low-impulsive participants performed better with respect to absolute error on the transfer test, while high-impulsive individuals performed better with respect to relative error on the transfer test.

The lack of significant interaction effects between type of KR and level of impulsivity was unexpected. In both dimensions to be learned, very small effect sizes during acquisition and learning tests were observed. When separately analyzing each factor, impulsivity seemed to have a larger learning influence than type of KR on the transfer test findings. The transfer test sets two different challenges to the learner: (a) the production of a new value of parameter based on the previous experience gained during acquisition and (b) the maintenance of the temporal relationship between the movement components. While an engagement in controlled processing, independently of type of KR, was associated with a better capacity of generation of a new parameter, the impulsive processing style was associated with better maintenance of the movement pattern.

Controlling a new motor skill requires a large amount of cognitive effort, mainly in the initial learning stages (Krause et al., 2017). The way in which the learner attends to the temporal goals of the task and requests KR after good, bad, or equally between good and bad trials can increase or decrease this high demand on cognitive control. Low-impulsive learners of both groups switched their direction of attention from the initial and middle parts of acquisition to the last part, using a strategy to increase attentional effort only after the skill was better controlled. The decreased PT observed throughout practice gives some support to this "gain of control" hypothesis. Most participants (73%) in the low-impulsive self-controlled group finished the acquisition phase directing their attention to both dimensions, and this pattern was also shown by 66% of the low-impulsive yoked group. Despite its high attentional cost, this strategy seems to be adequate considering the need to learn both relative and absolute temporal dimensions, though it may depend on good self-regulation that is associated with a sensitive and adaptable approach (Lohman & Bosma, 2002). Although the dynamic strategy seems to represent information processing, it best facilitates absolute dimension learning.

The same dynamic strategy was not observed among high-impulsive participants. Impulsive or controlled behavior seems to represent an inherent disposition toward a particular cognitive style (Nietfeld & Bosma, 2003). A core characteristic of more impulsive individuals is difficulty inhibiting prepotent thoughts and behaviors (Hofmann, Schmeichel, & Baddeley, 2012; Malloy-Diniz et al., 2013). Prepotent behavior may refer to habitual or automatized responses (Lage et al., 2012). While most high-impulsive learners of the self-controlled KR group shifted their attention to direct it primarily to the relative dimension, high-impulsive participants in the yoked group maintained the same direction of attention throughout practice on the relative dimension or equally to both dimension. The strategy of maintaining the direction of attention during acquisition could be interpreted as an inefficient self-regulation within the contextual task demands in this study, but this strategy at least led to better performance in the relative dimension on the transfer test. Similarly, although impulsivity has generally been viewed as counterproductive (Lage, Albuquerque, Fuentes, Corrêa, & Malloy-Diniz, 2013; Stanford et al., 2009), some studies have shown a positive benefit to impulsivity in some specific learning contexts, as, for example, when tasks present high temporal and spatial demands to the motor system (Lage et al., 2011, 2012). Our study's results further suggest that a specific learning dimension (relative movement timing) can be favored by an impulsive cognitive style.

Examining the self-controlled KR groups, low-impulsive learners requested more KR than their high-impulsive counterparts. We expected this finding since impulsive processing requires little cognitive effort and controlled processing requires high cognitive capacity (Richetin & Richardson, 2008; Strack & Deutsch, 2004). We also found that the participants' KR request strategies related to good and bad trials differed between participants with different processing styles. While low-impulsive participants reported preferring KR after good trials or equally after good and bad trials, high-impulsive participants mostly preferred KR after good trials throughout the acquisition phase.

Past studies have sometimes found no clear preference KR requesting strategy (Aiken, Fairbrother, & Post, 2012; Carter & Patterson, 2012; Patterson, Carter, & Sanli, 2011) and a clear preference for KR after good trials (Bokums, Meira., Neiva, Oliveira, & Maia, 2012; Chiviacowsky & Wulf, 2002, 2005; Fairbrother, Laughlin, & Nguyen, 2012). Requesting KR after bad trials suggests that the learner is engaged in a deliberative problem-solving strategy that requires greater cognitive effort. The high cognitive cost strategy of requesting KR equally after good and bad trials seems to better fit the low-impulsive learner's controlled processing style, linking KR benefits to KR's informational value. This strategy facilitates the development of a mechanism of error detection and movement correction (Carter & Patterson, 2012). Therefore, the development of performance estimation added to an efficient self-regulation of attention to both dimensions of the task seems to strengthen an accurate and adaptable memory representation, facilitating transfer to a new parameter value. On the other hand, maintaining the directing of attention to the relative dimension throughout practice and the high-impulsive learners' preference for KR after good trials strengthened their accurate and stable memory representation to facilitate an acquisition of the structure of movement during acquisition, even while hindering later transfer learning.

Also concerning self-controlled KR, the better maintenance of the movement structure in transfer showed by the yoked participant groups was unexpected and challenges the logic usually proposed in self-controlled studies. The active involvement of learners in their own learning process has been recognized as one of the most influential aspects of motor learning (Marques & Corrêa, 2016). Yet, we found an opposite result, in which receiving KR without the need to decide about it produced a better maintenance of the relative dimension of the task on transfer testing. Some other negative results regarding self-controlled feedback have been found in the literature in specific populations, such as among children (Chiviacowsky, Neves, Locatelli, & Oliveira, 2005), elderly participants (Chiviacowsky, de Medeiros, Schild, & Afonso, 2006), and people with anxiety (Bokums et al., 2012). Chiviacowsky et al. (2005) found, in a similar sequential motor learning task with relative and absolute timing goals, an advantage for the yoked group in learning relative dimension during the retention test; and these authors discussed this result as an exception related to the particular characteristics of children's information processing, perhaps similar to the particular information processing characteristics of interest in our study—those related to impulsivity. A descriptive analysis of our participants' performance on the transfer test shows a superior performance obtained by the high-impulsive yoked group in comparison to the other yoked group. Therefore, some interaction between the economic cognitive style of high-impulsive participants and externally controlled KR can be speculated. The attentional directing of the high-impulsive yoked group did not change during acquisition. High-impulsive learners of the yoked group directed their attention to the relative dimension or equally to both dimensions, and this stereotyped behavior can favor learning of the structure of movement.

Although our results did not show benefits of self-controlled KR in motor learning, we found an interesting result that reinforces some difference in participants' information processing. The higher PT shown by self-controlled KR participants compared with the externally controlled KR participants during acquisition phase seems to indicate what is called a deeper level of information processing (Janelle et al., 1995). The option to ask or not ask for KR demands a higher allocation of cognitive resources. Future studies should further investigate differences in perceptual and cognitive load when the learner has the option to ask or not for KR and their relation to information processing styles. Perceptual load is known to be associated with allocating processing resources of information gathering, visual scanning, and sustained attention, and cognitive load is related to working memory load, integration of information, and problem-solving (Lelis-Torres et al., 2017)

The study of processing styles usually gives more emphasis to the processes involved in performance than to the level of performance (Messick, 1994), but the present study contributes to an understanding of how individual differences in processing influence motor learning performance. Despite not finding expected interactions between impulsive and controlled styles of processing and types of KR on our two performance measures, we observed relevant findings regarding processes involved in motor learning. Different learning strategies related to the direction of attention were used by the participants with two different cognitive styles such that low-impulsive learners adopted a more demanding strategy not only by directing attention to different dimensions of the task but also by requesting more KR than their high-impulsive counterparts. Moreover, this is the second study using a sequential motor task to find benefits of externally controlled KR over the self-controlled KR in the relative dimension, and our data suggest a need to further research whether there may be a benefit to a high-impulsive style in this specific learning realm when KR is externally controlled.

Among this study's limitations are the limited number of direct measures for inferring cognitive engagement. Moreover, a high number of trials of the motor task under a constant practice condition during the acquisition phase might have contributed to the similarity of the groups' performances on the retention test. An extensive constant practice might have led to a strong consolidation of the learning regardless of the level of impulsivity or the type of KR. Despite these limitations, our results indicated that lower or higher levels of impulsivity in a nonclinical population can differently affect motor learning, highlighting the relevance of individual differences in the learning process. In conclusion, this study promotes a better understanding of the impact of impulsivity on motor skills learning, such that lower or higher impulsivity favors learning distinct task dimensions. Low-impulsive learners performed better when changes in the absolute dimension were required, as their dynamic cognitive strategy seemed to give them greater behavioral flexibility throughout practice. On the other hand, fast information processing associated with poor cognitive flexibility of high-impulsive individuals led these participants to perform better when the task demands favored maintenance of the relative dimension and changes in the absolute dimension. In general, this study indicates that learner impulsivity can affect the learning of sequential motor skills regardless of whether the KR is self- or externally controlled.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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