Is the motivational pillar of OPTIMAL theory indeed motivating? A quantitative appraisal of the existing evidence

Juliana O. Parma[1*]; Matthew W. Miller[2,3]; Mariane F. B. Bacelar[3*]

[1] Department of Kinesiology, San Francisco State University, 1600 Holloway Avenue, San Francisco, CA, 94132, USA

[2] School of Kinesiology, Auburn University, 301 Wire Road, Kinesiology Building, Auburn, AL, 36849, USA

[3] Center for Neuroscience Initiative, Auburn University, Auburn, AL, USA

[4] Department of Kinesiology, Boise State University, 1910 University Drive, Boise, ID 83725-1710, USA

*Corresponding author: julianaparma@sfsu.edu, marianebacelar@boisestate.edu

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Abstract

Motivation is commonly recognized by researchers and practitioners as a key factor for motor learning. The OPTIMAL theory of motor learning (Wulf & Lewthwaite, 2016) claims that practice conditions that enhance learners' expectancies for future successful outcomes or that are autonomy supportive are motivating, thus leading to better learning. To examine the current evidence of the association between motivation and motor learning, we searched the literature for studies that manipulated expectancies and/or autonomy support. Specifically, our goals were to assess whether these manipulations resulted in group differences in motivation and, if so, whether increased motivation was associated with learning advantages. Results showed that out of 166 experiments, only 21% (n = 35) included at least one measure of motivation, even though this is the main factor proposed by OPTIMAL theory to explain the learning benefits of these manipulations. Among those, only 23% (n = 8) found group-level effects on motivation, suggesting that these manipulations might not be as motivating as expected. Of the eight experiments that found a group-level effect on motivation, five also observed learning benefits, offering limited evidence that when practice conditions increase motivation, learning is more likely to occur. Overall, the small number of studies assessing motivation precludes any reliable conclusions on the association between motivation and motor learning from being drawn. Together, our results question whether manipulations implemented in the research lines supporting OPTIMAL theory are indeed motivating and highlight the lack of sufficient evidence in these literatures to support that increased motivation benefits motor learning.

Keywords: skill acquisition; self-controlled learning; enhanced expectancies; intrinsic motivation; self-efficacy

Introduction

Motivation refers to all factors that drive and direct one's behavior (Keller & Burkman, 1993). When it comes to motor skill acquisition, this psychological construct is commonly recognized by researchers and practitioners as a critical factor for motor learning. Although much of this belief stems from anecdotal evidence grounded in personal experiences, at a neural level, increased dopaminergic activity in the striatum is often associated with motivation (Daniel & Pollmann, 2014). The striatum is a brain region modulated by the reward system that has been shown to play an important role in the selection of the appropriate procedural memory (Cataldi et al., 2022) and consolidation of goal-directed movements (Choi et al., 2020). For instance, Widmer et al. (2016) demonstrated that practice sessions that result in stronger striatal activation lead to better motor skill retention.

Despite the shared cortical pathway between the reward and the motor systems (Cataldi et al., 2022) and the presence of anecdotal evidence, the role of motivation in skill acquisition has been traditionally overlooked by motor learning researchers. After the development of several theories and motor learning models that focused mostly on the effects of information processing on skill acquisition, the potential benefits of motivation for motor learning were finally formalized by the Optimizing Performance Through Intrinsic Motivation and Attention for Learning (OPTIMAL) theory (Wulf & Lewthwaite, 2016). OPTIMAL theory claims that practice conditions that enhance learners' expectancies for future positive outcomes and/or that are autonomy supportive are motivating, since they fulfill the human basic psychological needs to feel competent and autonomous, respectively. The association between basic psychological needs and motivation is the premise behind self-determination theory (Deci & Ryan, 2000), which claims that motivation is enhanced when one or more basic psychological needs are fulfilled. Consistent with this theoretical framework, OPTIMAL theory suggests that learners' sense of autonomy can be supported through a number of strategies throughout the learning process, such as allowing learners to choose the feedback schedule (e.g., Ferreira et al., 2019), the number of trials to be performed (e.g., Lessa & Chiviacowsky, 2015), or the color of the implement used (e.g., McKay & Ste-Marie, 2022). Similarly, according to the theory, learners' expectancies are enhanced through the provision of feedback after good trials (e.g., Carter et al., 2016), positive social-comparative feedback (e.g., Grealy et al., 2019), and/or by lowering learners' perceptions of task difficulty (e.g., Parma et al., 2023), to cite a few strategies. Together, enhancing expectancies and supporting autonomy constitute the motivational pillar of OPTIMAL theory, and, as such, are predicted to increase goal-action coupling and dopamine availability for memory consolidation during and after practice, causing neuroplastic changes that ultimately result in better performance and learning.

Recently, three meta-analyses (Bacelar, Parma, Murrah et al., 2022; McKay et al., 2022; McKay et al., 2023) assessed the learning benefits associated with the motivational pillar of OPTIMAL theory. Notably, the collective evidence questions whether enhancing expectancies and supporting autonomy are, indeed, beneficial for learning. For instance, the most recent meta-analysis by McKay et al. (2023) found weak evidence of the benefits of enhanced expectancies and moderate evidence against the benefits of autonomy support on motor learning after sampling 48 studies (56 outcomes) manipulating enhanced expectancies and 47 studies (52 outcomes) investigating autonomy support. Specifically, enhanced expectancies and autonomy support were estimated to have, together, a small and non-significant effect on learning as indexed by performance at a delayed (≥24h) retention test {enhanced expectancies: d = .26 (95% credible interval [-.07, .63]; autonomy support: d = .034 (95% credible interval [.0, .248])}.

Crucially, these meta-analyses only focused on the behavioral effects of these manipulations, leaving aside the main mechanism proposed by OPTIMAL theory to underlie the learning effect. If these manipulations are expected to result in learning benefits through increased motivation, learning effects are, in theory, conditioned upon whether these manipulations lead to significant changes in levels of motivation. However, to our knowledge, no study has investigated the effects associated with the motivational pillar of OPTIMAL theory through this mechanistic lens. If the body of studies under this pillar is not observing significant group differences in motivation levels, this could possibly explain the lack of behavioral benefits found by McKay et al. (2023)'s meta-analysis. Therefore, in this study we reviewed the existing literature to gather evidence to support the motivating value of the manipulations forming the evidentiary basis of the motivational pillar of OPTIMAL theory. Additionally, we investigated whether group differences in motivation across enhanced expectancies and autonomy support studies were associated with learning effects. To achieve these objectives, first we examined whether studies manipulating enhanced expectancies and/or autonomy support measured motivation. Next, across experiments that included a measure of motivation, we assessed whether the manipulation(s) resulted in a group-level effect on motivation. Lastly, among the experiments that were successful in manipulating motivation, we examined whether the experimental group also demonstrated better learning. According to OPTIMAL theory's claims and predictions, we hypothesized that manipulations of autonomy support and enhanced expectancies would result in a group-level effect of motivation favoring the experimental group, and that learning advantages would accompany this effect in the same direction.

Methods

Data and code for this study are freely available at [https://osf.io/3hdkg/?view_only=f7973266851f481e809f72b706221890].

Study eligibility criteria

The meta-analyses by Bacelar, Parma, Murrah et al. (2022) and McKay et al. (2022) comprise, respectively, the most recent quantitative syntheses of the enhanced expectancies and autonomy support literatures. Thus, we opted for using the same inclusion criteria described in these meta-analyses, with one exception. Different from Bacelar, Parma, Murrah et al.'s meta-analysis, McKay et al.'s included studies accepted as part of master's theses or PhD dissertations. In the present study, however, we focused on studies published in peer-reviewed journals for two reasons. Firstly, since OPTIMAL theory is grounded in evidence from *peer-reviewed, published* studies, we reasoned that this approach would evaluate the types of studies on which OPTIMAL theory was based. Secondly, our main goal was to offer an overview of the methods and overall results across studies that have gone through a rigorous screening and review process, which should lead to high-quality end products.

Table 1 summarizes shared and unique inclusion criteria in Bacelar, Parma, Murrah et al. (2022) and McKay et al. (2022)'s meta-analyses.

Shared Inclusion Criteria	
Experimental design At least one delayed (≥ 24-hr) retention test Assessed an objective behavioral measure Published in a peer-reviewed journal	
Unique Inclusion Criteria	
Enhanced Expectancies (Bacelar, Parma, Murrah et al., 2022)	**Self-controlled Practice (McKay et al., 2022)**

Included an enhanced expectancies group	Included a self-control group
Included a control or diminished expectancies group	Included a yoked group
Included a learnable, goal-directed motor task	Included theses and dissertations

Literature search strategy

Since our approach consisted of building upon Bacelar, Parma, Murrah et al. (2022)'s and McKay et al. (2022)'s study selection strategy, all the studies included in the meta-analyses' quantitative synthesis were also included in the present investigation (see more details below). To gain access to a more comprehensive pool of studies, we expanded Bacelar, Parma, Murrah et al.'s and McKay et al.'s search strategies to include enhanced expectancies studies published between June of 2020 and December of 2023 (Bacelar, Parma, Murrah et al.'s last date of search was June 19, 2020) and autonomy support studies published between August of 2019 and December of 2023 (McKay et al.'s last date of search was August 2, 2019). Our literature search strategy replicated the ones adopted in the aforementioned meta-analyses. Specifically, we used the same terms, search strings, and filters to search for papers in the same electronic databases (i.e., Enhanced expectancies: PsycINFO, Web of Science, and PubMed; Autonomy support: PubMed and Google Scholar). A detailed description of the search strategy used for each literature can be found on the project's Open Science Framework (OSF) page [https://osf.io/3hdkg/?view_only=f7973266851f481e809f72b706221890].

Study identification and selection

A detailed description of the study selection process is included in the PRISMA (Page et al., 2021) flow diagram below (Figure 1). Study identification was carried out using three methods: identification via previous reviews, identification of new studies via databases, and identification via other methods (i.e., personal records). Regarding the former, all 48 studies included in the enhanced expectancies meta-analysis and 35[1] studies included in the autonomy support meta-analyses were also included in our quantitative synthesis. Additionally, studies excluded from these meta-analyses due to missing data were reevaluated. We reasoned that these studies may have reported enough information to justify their inclusion in the present study given our distinct quantitative methods. This reevaluation led to the inclusion of 23[2] additional studies. Our second study identification method consisted of searching for studies in the databases during the publication period not covered by the previous meta-analyses. Specifically, authors J.O.P. and M.F.B.B. independently searched for new articles using the search strategies reported in Bacelar, Parma, Murrah et al. (2022)'s and McKay et al. (2022)'s meta-analyses. The new query resulted in the identification of 690 studies in the enhanced expectancies search and 404 studies in the autonomy support search. Regarding the latter, the initial Google Scholar search resulted in 17,100 records but only the first 300 were retrieved. This decision was made after J.O.P. and M.F.B.B. searched for potential hits across several pages of results and agreed to quit searching at the end of page 30, following an extended period of zero hits. After duplicate removal, the title and abstract of the 629 studies remaining were screened. Next, 101 studies had their full text screened for eligibility according to our inclusion criteria, which resulted in 46 new studies being added to the quantitative synthesis. Finally, 8 studies identified through personal records were also included in the quantitative synthesis. Across all study identification and selection methods, 158 unique[3] studies were included in the present investigation.

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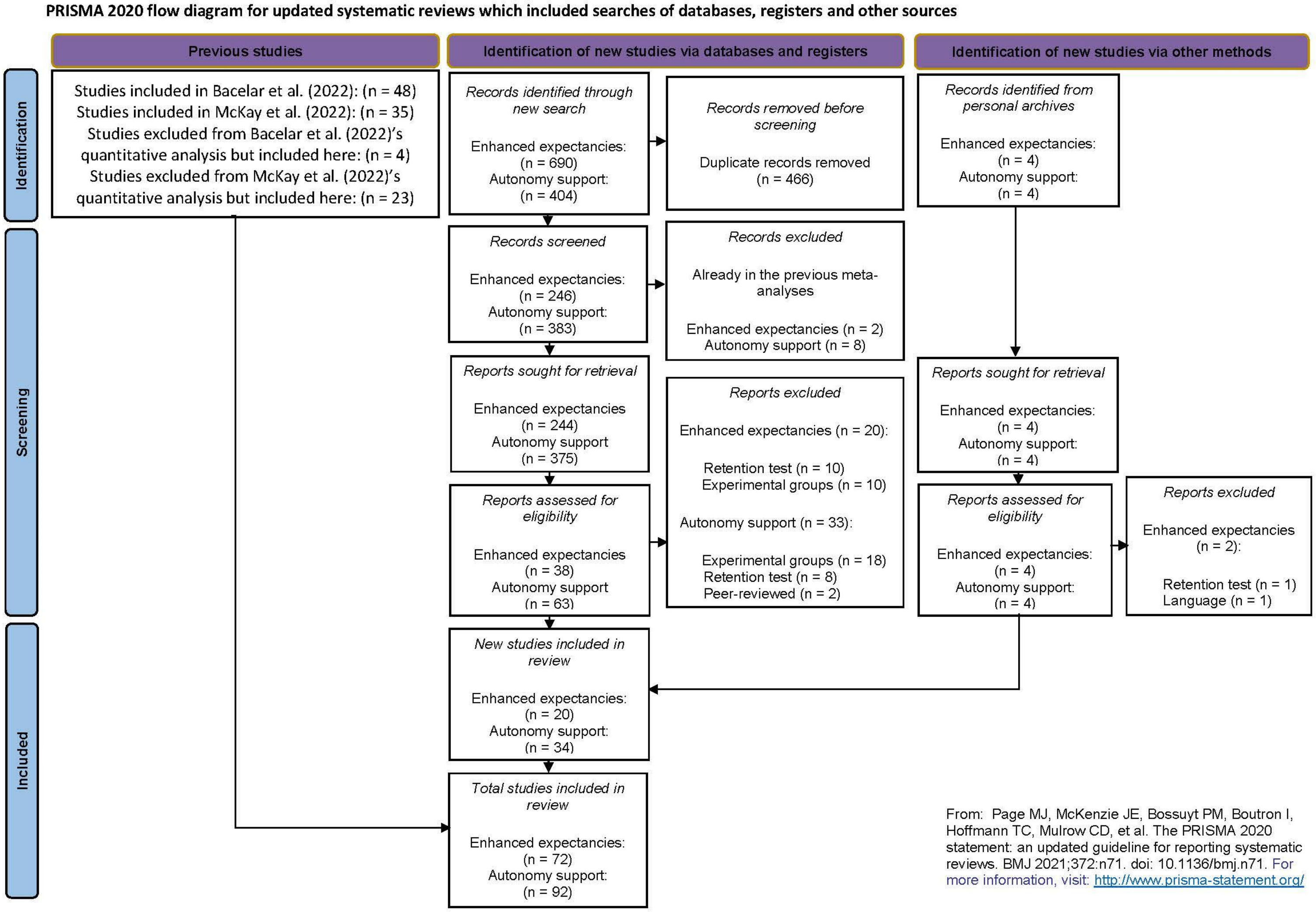
[1] McKay et al. (2022)'s meta-analysis originally included 36 articles. However, during the screening process, we determined that the article by Ali et al. (2012) did not meet one of the inclusion criteria, namely the presence of a delayed retention test, which resulted in the article's exclusion from the present investigation.

[2] Upon reevaluation of the 24 published studies excluded from McKay et al. (2022)'s quantitative synthesis, we determined that Wu and Magill (2011) was the only one that could not be included because it did not meet one of the inclusion criteria, namely the presence of a delayed retention test.

[3] The number of enhanced expectancies and autonomy support studies included in the quantitative synthesis as presented in the PRISMA flow diagram does not add up to 158 because six studies manipulated enhanced


PRISMA 2020 flow diagram for updated systematic reviews which included searches of databases, registers and other sources

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71. For more information, visit: http://www.prisma-statement.org/

Figure 1. PRISMA Flow Diagram. Figure depicting the flow of information through the different steps of literature search and study selection (Page et al., 2021).

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expectancies and autonomy support in the same experiment, so these studies met the inclusion criteria for both literatures. Please note that studies that manipulated enhanced expectancies and autonomy support may also be double counted at each step in the Prisma flow diagram.

Data extraction and analysis

To address our main research questions, we extracted information about 1) whether motivation was measured in the experiments reported, and 2) if so, if there was a group-level effect on motivation and 3) learning as indexed by significant differences in performance in the delayed retention test. For experiments that measured motivation at multiple time points (e.g., during acquisition and before retention, e.g., Aiken et al., 2020; Lessa et al., 2018), we recorded group differences in motivation (if present) at any given point. For experiments that included more than one delayed retention test (≥24hr, e.g., Kok et al., 2020; Mousavi et al., 2021), we recorded the learning effect if group differences were observed at any of the retention tests regardless of the delayed period. Importantly, we did not assess the adequacy of the statistical analyses used in the experiments. Instead, we simply recorded the results of the analyses as reported in the manuscript. For experiments that reported more than one outcome measure, we selected the measure more closely associated with accuracy, aligned with the approach adopted by the previous meta-analyses (Bacelar, Parma, Murrah et al., 2022, McKay et al., 2022).

To better understand the current state of the literature that investigates the relationship between motivation and learning, we also extracted information about the direction of the motivation effect (e.g., experimental group showed higher levels of motivation), the type of measurement used to assess motivation (e.g., questionnaire), the time of measurement (e.g., during acquisition, before retention, etc.), and the direction of the learning effect (e.g., favored the experimental manipulation), which was used for secondary analyses. To compose our descriptive table, we collected information about manipulation, population, sample size, type of task, and retention interval.

The research questions were addressed descriptively through the calculation of proportions. All analyses and data visualizations were conducted in R (version 4.3.2, R Core Team, 2021) using the following packages: patchwork (version 1.2.3; Pedersen, 2024), tidyverse (version 2.0.0; Wickham et al., 2019), and waffle (version 1.0.2; Rudis & Gandy, 2019).

Results

Overview of pool of studies

Of the 166 experiments reported in 158 articles, 69 manipulated expectancies, 92 manipulated autonomy support, and five manipulated both. The publication period of the enhanced expectancies literature consisted of 16 years, spanning from 2007 to 2023, whereas the publication period of autonomy support literature consisted of 26 years, spanning from 1997 to 2023. Regarding the type of population studied, 25 experiments were done with children/adolescents, 122 with adults, nine with older adults, seven with special populations (e.g., patients with Parkinson's Diseases, children with cerebral palsy), and three experiments sampled two different populations.

Main analyses

Of the 166 experiments included in the analyses, only 21% (n = 35) measured motivation, 19 from the autonomy support literature and 16 from the enhanced experiences literature (see Figure 2). Across the experiments that measured motivation, 71% (n = 25) did not find a group-level effect on motivation, whereas 23% (n = 8) did, all in the expected direction (i.e., favoring the OPTIMAL theory manipulation). Two experiments (6%), one from each literature, did not report results associated with the motivation measures. The proportion of experiments that manipulated autonomy support and found a group-level effect of motivation was greater (26%, n = 5) than the proportion of studies that manipulated expectancies and found the motivation effect (19%, n = 3). Across the eight experiments that showed a group-level effect on motivation, five also observed a significant group-level learning effect in the expected direction (i.e., favored the OPTIMAL theory manipulation), four autonomy support experiments and one enhanced expectancies experiment (Figure 3). Another enhanced expectancies experiment also observed a partial dual effect (motivation and learning). Specifically, in the study by Chiviacowsky et al. (2012), even though the enhanced expectancies group showed higher levels of motivation compared to both control and diminished expectancies groups, the experimental group outperformed only the diminished expectancies group in the retention test. Finally, across the 25 experiments that measured and did not find a group-level effect on motivation, nine found a learning effect favoring the OPTIMAL theory manipulation.

Figure 2. Number of experiments manipulating expectancies and/or autonomy support that measured motivation (orange) and that did not measure motivation (gray). Each square represents one experiment.

Secondary analyses

To better understand how motivation has been investigated in experiments that manipulated autonomy support or expectancies, we also conducted a qualitative assessment of our sample. Of interest to researchers studying the links between motivation and learning under an OPTIMAL theory framework may be the instruments used to assess motivation in existing studies. All but one of the experiments included in our sample measured motivation using a self-reported questionnaire. The exception was the study by Ikudome et al. (2019) wherein motivation was measured as the number of times participants engaged with the main task during their free time. Overall, the original or adapted interest/enjoyment subscale from the Intrinsic Motivation Inventory was the preferred method of assessment, although some studies adopted other validated questionnaires such as the Behavioural Regulations in Physical Education Questionnaire (Katz & Westera, 2019) and the Situational Motivation Scale (e.g., Ong et al., 2019). Customized questionnaires were adopted in some studies as well.

We also investigated when motivation was measured as a function of the experiment timeline. Although some variability was present, most experiments measured motivation once, and typically after the acquisition phase (for more details see Table 2). Across the eight experiments that found a group-level effect on motivation, all of them included a measure of motivation after the acquisition phase and six found an effect at that time point. Additionally, three of the eight experiments also measured motivation after the retention test(s), and two found an effect at that time point. Characteristics of the experiments that measured motivation can be found in table 2.

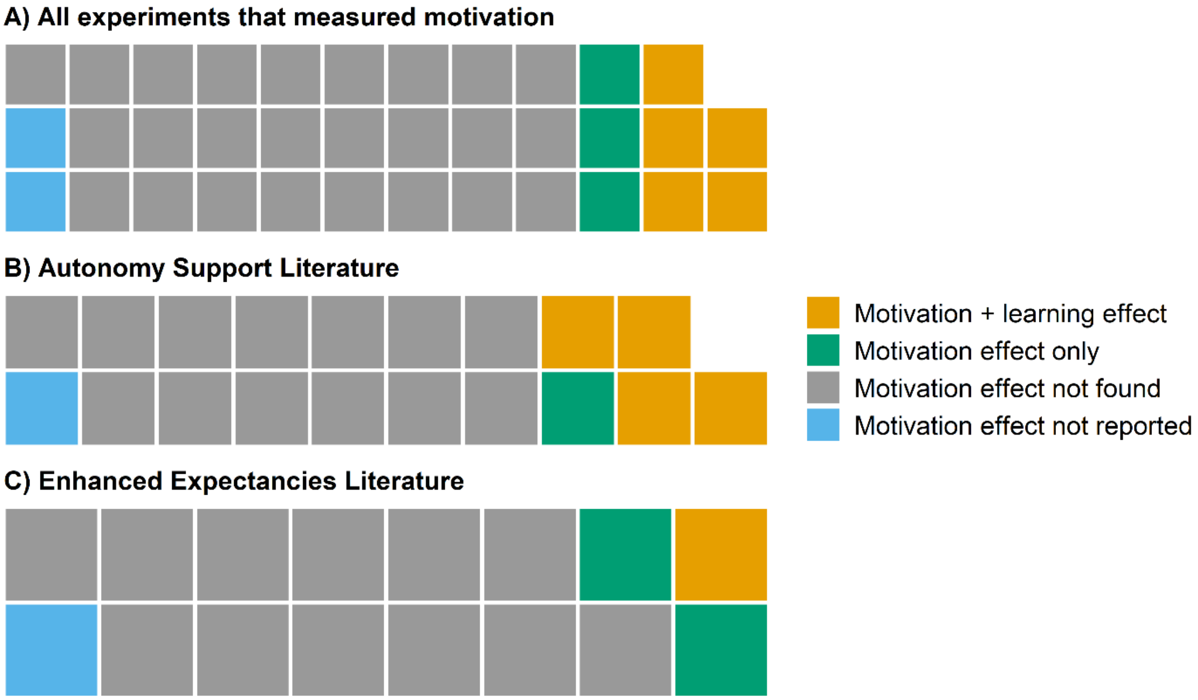

Figure 3. (A) Total number of experiments that measured motivation and found motivation and learning effects (orange); found a motivation effect but not a learning effect (green); found no motivation effect (gray); or did not report the motivation effect (blue). (B) and (C) represent the same data as in (A), divided by manipulation type: (B) represents the autonomy support literature and (C) represents the enhanced expectancies literature. Each square represents one experiment.

Discussion

Learners' level of motivation during practice is often a matter of concern for instructors, coaches, and practitioners as this factor is expected to influence the learning process. According to OPTIMAL theory, motivation can be fostered by enhancing learners' expectancies for future positive outcomes and/or by supporting learners' sense of autonomy. Such manipulations are proposed to trigger dopaminergic responses in the central nervous system, ultimately resulting in increased motor memory consolidation. Notably, collective evidence from recent meta-analyses on the topic (Bacelar, Parma, Murrah et al., 2022; McKay et al., 2022; McKay et al., 2023) questions the learning benefits of the motivational manipulations described in OPTIMAL theory. However, according to the theory, the learning benefits are contingent upon the effective modulation of motivation, a variable not examined in the meta-analyses. To address this knowledge gap, in the present study we reviewed the existing literature to investigate whether manipulations associated with the motivational pillar of OPTIMAL theory are indeed motivating and, if so, whether increased motivation is associated with motor learning benefits.

Grounded in OPTIMAL theory's claims, we hypothesized that manipulations of enhanced expectancies and/or autonomy support would result in increased motivation. This prediction, however, was not supported by our results as the majority (25/35) of the experiments that measured motivation did not find a group-level effect on it. These findings suggest that the practice conditions associated with the motivational branch of OPTIMAL theory may not be as

Table 2

Summary of the main characteristics of the studies included in the meta-analysis

Authors (year)	Manipulation type	Population experience level; age group (Age mean ± SD)	Total sample size	Task	Type of measure of motivation	Motivation measurement time	Group-level motivation effect	Direction of group effects on motivation	Ret. time	Group-level learning effect	Direction of group-level learning effect	Group-level motivation & learning effect
Autonomy Support												
Aiken et al. (2020)	Amount of practice and pacing	Novices; adults (21.28yr. ± 4.65)	56	Sequential timing	IMI (interest/enjoyment subscale – adapted)	After acq.; after ret.	No	NA	24h	Yes	Favored the manipulation	NA
Bacelar, Parma, Cabral et al. (2022)	Knowledge of results	NR; adults (20.64yr. ± 1.6)	200	Beanbag tossing	IMI (interest/enjoyment subscale – original)	After acq.	No	NA	24h	No	NA	NA
Barros et al. (2019, exp. 2)	Knowledge of results	Novices; adults (21.32yr. ± 2.03)	60	Rapid extension-flexion reversal movement	IMI (interest/enjoyment subscale – original)	During acq.; after acq.	No	NA	24h	No	NA	NA
Batista et al. (2022)	Knowledge of results	Novices; adults (25.25yr. ± 3.63)	40	Underhand dart-throwing	IMI (interest/enjoyment subscale – original)	After acq.	No	NA	24h	Yes	Favored the manipulation	NA
Chiviacowsky et al. (2012)	Assistive device	Novices; adults with Parkinson's disease (46-88yr.)	28	Balancing on a stabilometer	Customized questionnaire (2 items)	After acq.; after ret.	Yes (after acq. only)	After acq.: Favors the manipulation	24h	Yes	Favored the manipulation	Yes
Goudini et al. (2019)	Knowledge of performance	Novices; teenagers (12.43yr. ± 2.08)	30	Taekwondo's Ap chagi technique	IMI (interest/enjoyment subscale – adapted)	After acq.	Yes	Favors the manipulation	48h	Yes	Favored the manipulation	Yes

Authors (year)	**Manipulation type**	**Population experience level; age group (Age mean ± SD)**	**Total sample size**	**Task**	**Type of measure of motivation**	**Motivation measurement time**	**Group-level motivation effect**	**Direction of group effects on motivation**	**Ret. time**	**Group-level learning effect**	**Direction of group-level learning effect**	**Group-level motivation & learning effect**
Grand et al. (2015)	Knowledge of results	Novices; adults (23.1yr. ± 3.16)	36	Beanbag tossing	IMI (interest/enjoyment subscale – original)	After acq.	No	NA	24h	No	NA	NA
Grand et al. (2017)	Incidental	NR; adults (21.7yr. ± 2.09)	68	Beanbag tossing	IMI (interest/enjoyment subscale – original)	After acq.	No	NA	1 week	No	NA	NA
Ikudome et al. (2019, exp. 2)	Model demonstration	Novices; adults (19.9yr. ± 0.98)	40	Dart-throwing	Quantity of practice in 5min of free practice	After acq.	No	NA	24h	Yes	Favored the manipulation	NA
Jaquess et al. (2021)	Repetition schedule	Novices; adults (21.7yr. ± 3.98)	32	Golf putting	Customized visual analogue scale (2 items)	During acq.; after acq.	NA	NA	24h	No	NA	NA
Katz & Westera (2019)	Task strategy selection, monitoring and evaluation of task execution, and assessment of performance	Novices; teenagers (13.4yr. ± 0.6)	150	Touch somersault	BRPEQ (intrinsic regulation and introjected regulation; external regulation and identified regulation; amotivation subscales, original)	After ret.	No	NA	1 week	Yes	Favored the manipulation	NA
Kok et al. (2020)	Self-modelling	Novices; teenagers (12.7yr. ± 0.63 months)	56	Shot-put	Customized visual analog scale of perceived enjoyment (1 item)	After acq.	No	NA	1 week and 2 weeks	No	NA	NA
Leiker et al. (2016)	Task difficulty	NR; adults (21.1yr. ± 1.96)	60	Computer game	IMI (interest/enjoyment subscale – original)	After acq.	Yes	Favors the manipulation	1 week	Yes	Favored the manipulation	Yes

Authors (year)	Manipulation type	Population experience level; age group (Age mean ± SD)	Total sample size	Task	Type of measure of motivation	Motivation measurement time	Group-level motivation effect	Direction of group effects on motivation	Ret. time	Group-level learning effect	Direction of group-level learning effect	Group-level motivation & learning effect
Leiker et al. (2019)	Task difficulty	Novices; adults (NR yr.)	60	Computer game	IMI (interest/enjoyment subscale – original); Customized questionnaire (1 item)	IMI: after acq. Customized questionnaire: during acq.; after acq.	Yes (customized questionnaire only, on average)	Favors the manipulation	5 – 9 days	No	NA	No
Post et al. (2016)	Split-screen performance replay with expert model demonstration	Novices; adults (21.8yr. ± 1.3)	44	Golf-chipping	IMI (interest/enjoyment subscale – original)	Before acq.; during acq.; after acq.; after ret.	No	NA	24h	No	NA	NA
St. Germain et al. (2022)	Demonstration and speed	NR; adults (18.9yr. ± 1.26)	150	Cup stacking	IMI (interest/enjoyment subscale – original)	Before acq.; during acq.; before ret.	No	NA	24h	No	NA	NA
St. Germain et al. (2023, exp. 1)	Knowledge of results	NR; adults (20.64yr. ± 2.45)	152	Out and back reversal movement with manipulandum	IMI (interest/enjoyment subscale – original)	Before acq.; during acq.; after acq.; before ret.	No	NA	24h	No	NA	NA
St. Germain et al. (2023, exp. 2)	Knowledge of results	NR; adults (20.18yr. ± 3.18)	76	Out and back reversal movement with manipulandum	IMI (interest/enjoyment subscale – original)	Before acq.; during acq.; after acq.; before ret.	No	NA	24h	No	NA	NA
Ste-Marie et al. (2013)	Self-observation	NR; children (11.2yr. ± 1.89)	60	Trampoline routine	IMI (interest/enjoyment subscale – original)	During acq.; after acq.; after ret.	Yes (after ret. only)	After ret.: Favors the manipulation	24h	Yes	Favored the manipulation	Yes
Enhanced Expectancies												

Authors (year)	Manipulation type	Population experience level; age group (Age mean ± SD)	Total sample size	Task	Type of measure of motivation	Motivation measurement time	Group-level motivation effect	Direction of group effects on motivation	Ret. time	Group-level learning effect	Direction of group-level learning effect	Group-level motivation & learning effect
Abbas & North (2018)	Positive feedback	Novices; adults (29.67yr. ± 9.36)	30	Golf putting	IMI (interest/enjoyment subscale – adapted)	Before acq.; after acq.; after ret.	Yes (after ret. tests only)	Favors the manipulation	24h and 1 week	Yes (1 week ret. only)	Favored the manipulation	Yes
Bacelar et al. (2020)	Rewards	Novices; adults (20.7yr. ± 2.63)	69	Golf putting	IMI (interest/enjoyment subscale – original)	After acq.	No	NA	24h and 1 week	No	NA	NA
Chiviacowsky et al. (2019)	Comparative feedback	Novices; adults (23.2yr. ± 6.71)	28	Golf putting	IMI (interest/enjoyment subscale – adapted)	After acq.	No	NA	24h	Yes	Favored the manipulation	NA
Chiviacowsky et al. (2012)	Perceived task difficulty	Novices; adults (21.9yr. ± 3.36)	51	Anticipatory timing	IMI (interest/enjoyment subscale – original)	After acq.	Yes	Favors the manipulation	24h	Yes	Favored the manipulation	Partially (compared to diminished expectancies only, not control)
Chung et al. (2020)	Conceptions of ability and perceived task difficulty	NR; adults and older adults with Parkinson's disease (62.36yr. ± 9.80)	44	Balance on a stabilometer	Customized questionnaire (2 items)	After acq.	No	NA	24h	No	NA	NA
Drews et al. (2020)	Positive feedback	Novices; children (10.43yr. ± NA months)	30	Pedalo riding	IMI (interest/enjoyment subscale – adapted)	After acq.; before ret.	No	NA	24h	No	NA	NA
Lessa et al. (2018)	Comparative feedback	Novices; older adults (66.14yr. ± 5.06)	34	4-meter walking speed	IMI (interest/enjoyment subscale – adapted)	After acq.; after ret.	No	NA	24h	No	NA	NA

Authors (year)	Manipulation type	Population experience level; age group (Age mean ± SD)	Total sample size	Task	Type of measure of motivation	Motivation measurement time	Group-level motivation effect	Direction of group effects on motivation	Ret. time	Group-level learning effect	Direction of group-level learning effect	Group-level motivation & learning effect
Lewis et al. (2023)	Comparative feedback	NA; adults (18-40yr.)	48	Serial target	IMI (interest/enjoyment subscale – original)	Before acq.; after acq.; before ret.	No	NA	24h	No	NA	NA
Lewthwaite & Wulf (2010)	Comparative feedback	Novices; adults (23.0yr. ± 2.26)	36	Balance on a stabilometer	Customized questionnaire (4 items)	During acq.; after acq.	No	NA	24h	Yes	Favored the manipulation	NA
Ong et al. (2019)	Perceived task difficulty	Novices; adults (21.4yr. ± NA)	29	Dart-throwing	IMI (interest/enjoyment subscale – original), SMS (intrinsic motivation and amotivation subscales); Customized questionnaire (3 items)	IMI: After acq. SMS: After acq. Customized questionnaire: After acq.	No	NA	24h	No	NA	NA
Ong & Hodges (2018, exp. 2a)	Comparative feedback	Novices; adults (21.1yr. ± 3.4)	20	Balance on a stabilometer	IMI (interest/enjoyment subscale – original), SMS (intrinsic motivation and amotivation subscales); Customized questionnaire (2 items)	IMI: After acq. SMS: After acq. Customized questionnaire: After acq.	No	NA	24h	No	NA	NA
Parma et al. (2023)	Perceived task difficulty	Novices; adults (21.52yr. ± 2.7)	80	Mini-shuffleboard	IMI (interest/enjoyment subscale – original)	After acq.	Yes	Favors the manipulation	24h	No	NA	No
Patterson & Azizeh (2012)	Positive feedback	NR; adults (22.0yr. ± 1.15)	56	Slider positioning	Customized questionnaire (1 item)	After acq.	NA	NA	24h	No	NA	NA

Authors (year)	Manipulation type	Population experience level; age group (Age mean ± SD)	Total sample size	Task	Type of measure of motivation	Motivation measurement time	Group-level motivation effect	Direction of group effects on motivation	Ret. time	Group-level learning effect	Direction of group-level learning effect	Group-level motivation & learning effect
Saemi et al. (2011)	Positive feedback	Novices; children (10.61yr. ± 0.88)	28	Beanbag tossing	IMI (interest/enjoyment subscale – adapted)	After acq.	No	NA	24h	Yes	Favored the manipulation	NA
Wulf et al. (2012, exp. 1)	Comparative feedback	Novices; older adults (71.1yr. ± 5.25)	29	Balance on a stabilometer	Customized questionnaire (2 items)	After acq.; after ret.	No	NA	24h	Yes	Favored the manipulation	NA
Wulf et al. (2013)	Conceptions of ability and comparative feedback	Novices; adults (22.3yr. ± 2.25)	56	Balance on a stabilometer	Customized questionnaire (4 items)	During acq.; after acq.; after ret.	No	NA	24h	Yes (for comparative feedback only)	Favored the manipulation	NA

Note: *NR* indicates information was not reported. *NA* indicates information is not applicable. *Acq.* indicates acquisition phase. *Ret.* indicates retention test. *IMI* indicates Intrinsic Motivation Inventory. *BRPEQ* indicates Behavioural Regulations in Physical Education Questionnaire. *SMS* indicates Situational Motivation Scale. *SD* represents standard deviation.

motivating as expected. Notably, nine out of the 25 experiments that did not find a group-level effect on motivation still found learning benefits associated with the experimental manipulation(s). Overall, across the experiments that measured motivation, the proportion of those that found a group-level effect on motivation and learning benefits (5/8 or 62.5%) was greater than the proportion of experiments that did not find a group-level effect on motivation, but observed learning benefits (9/25 or 36%). This result might offer some limited evidence that, when practice conditions increase motivation, learning is more likely to occur. Alternatively, since learning was observed in both studies where motivation increased and in ones where it did not, it is possible that the observed learning effects were due to factors unrelated to motivation. For instance, the study by Barros et al. (2019) demonstrated that the group with control over the feedback schedule developed a better error estimation capability than the comparison group, a factor that was strongly correlated with learning. Thus, it is possible that giving learners control over feedback, a frequently adopted autonomy-support manipulation, might engage information processing mechanisms, which may contribute to trial-to-trial dynamics (e.g., exploration of new movement solutions) that ultimately contribute to learning. Along the same lines, manipulations that enhance expectancies may boost mechanisms underlying reward-prediction errors. According to reinforcement learning theory, successful outcomes result in positive reward-prediction errors (i.e., the difference between expected and actual outcomes), bringing about dopaminergic activity that increases the value of the precipitating action (Lohse et al., 2019). Once this process is repeated a number of times, the successful action is consolidated, increasing the chances of being re-selected in the future when the skill needs to be performed again. Thus, manipulations that enhance expectancies may create opportunities for this process to happen an optimal number of times during the practice session, which might explain the learning benefits found in some experiments. These alternative explanations are not meant and, very likely, do not account for all the possible mechanisms underlying the long-term motor skill retention observed in some autonomy support/enhanced expectancies experiments. Instead, our goal in offering these alternatives is to highlight the complex nature of the motor learning process, the understanding of which may require the use of a multi-mechanistic approach.

In an attempt to better understand the practices adopted in the experiments included in our sample, we conducted additional secondary analyses. Despite the very low number of experiments that measured motivation, we found a high level of consistency regarding the methods used to assess motivation. Specifically, the experiments that measured motivation did so using a self-reported measure (i.e., questionnaire), except for one. Unsurprisingly, the vast majority of them focused on assessing *intrinsic motivation*, which is the type of motivation expected to be increased when practice conditions support autonomy or feelings of competence (Wulf & Lewthwaite, 2016). It is possible, however, that autonomy support and enhanced expectancies manipulations affect other types of motivation to a greater extent. Self-determination theory (Deci & Ryan, 2000), which offers a framework for OPTIMAL theory, suggests that human motivation has six different facets that vary based on the individual level of autonomy or the extent to which people truly enjoy their actions. Given the restricted level of autonomy and pleasure present in lab studies (e.g., the volunteer is expected to be in the lab for a certain number of hours and cannot choose which task to perform), it is possible that intrinsic motivation is inherently less sensitive to manipulations than other types of motivation. Particularly, *identified motivation* refers to one's willingness to engage in an activity that may not be intrinsically enjoyable but that has a significant value and level of worthiness attributed to it, which seems to better describe the motives of a research participant that performs the experimental task. For example, the volunteer might engage in the task because they acknowledge the importance of contributing to the accumulation of scientific knowledge and, thus, might be more motivated to perform as well as possible so as to provide high quality data to the researchers, not because the task is pleasurable per se. In light of this possibility, we recommend that researchers interested in understanding the role played by motivation in the learning benefits associated with autonomy support/enhanced expectancies manipulations consider diversifying how motivation is assessed (e.g., incorporation of other behavioral measures; see Ikudome et al., 2019 for an example), and measuring other types of motivation.

Unfortunately, the low number of experiments that measured motivation in these literatures (35 out of 166) precluded the assessment of other variables of interest such as the strategy adopted to manipulate expectancies or autonomy, type of task, or type and time of motivation measurement used in these experiments. We expected to use this information to help clarify or better explain our findings, but we did not find clear patterns that distinguish the limited group of experiments that successfully modulated motivation (n = 8) from those that did not. It is surprising that the motivational role of enhanced expectancies and autonomy support manipulations is often assumed but not frequently demonstrated or assessed in these literatures. Given that motivation is the primary factor proposed by OPTIMAL theory to mediate the relationship between these manipulations and motor learning, these literatures could strongly benefit from a more consistent mechanistic check and construct validation. The fact that only eight experiments found group-level effects on motivation and that learning effects were only found in about half of them (5) prevents us from drawing any reliable conclusions on the association between motivation and motor learning. Therefore, although we expected that increased motivation would be accompanied by learning benefits in the experimental groups, at this point there is no sufficient evidence to support that increased motivation via OPTIMAL theory manipulations benefits motor learning. Assessing motivation in the enhanced expectancies and autonomy support literatures would enable better testing of OPTIMAL theory's predictions while increasing the construct validity of these studies. Construct validity is a necessity in experimental psychology and associated areas and refers to an experiment's ability to affect the psychological factors that it is intended to affect (Chester & Lasko, 2020). Although particularly highlighted in the present study, the lack of construct validation in motor learning is not an issue restricted to the enhanced expectancies and autonomy support literatures. For instance, Ranganathan et al. (2022) reviewed recent therapeutic interventions on stroke rehabilitation and listed the "ingredients" assumed by researchers to actively underlie and explain the success of their interventions. The authors found little correspondence between the number of active ingredients mentioned and those measured/reported in these experiments. Notably, motivation was one of the factors with the biggest discrepancy between these numbers, brought by frequent mentions of its role in rehabilitation but little accumulated evidence of its effects through measurement. Considering this pattern of results, we strongly encourage future studies using motivational manipulations to directly assess and report the effect of the manipulation on motivation, so that we gain insight into the relationship between motivation and motor learning.

While assessing whether manipulations under the motivational branch of OPTIMAL theory result in increased motivation at the group level is a crucial step moving forward, this is not the only matter that deserves attention. Researchers should also assess whether, at the individual level (controlling for group assignment), participants that report higher levels of motivation are also those who learn better. Motivation can only be considered a mediator in the relationship between these manipulations and learning when both effects are demonstrated

(Leiker et al., 2016; Carter et al., 2022). If the manipulation effects on motivation and learning are both demonstrated, but not the individual-level effect of motivation, this could indicate that the effects on learning are coincidental to the effects on motivation, but not *caused* by it. Although not part of our main objectives, we observed that only 8 of the experiments in our sample regressed motivation on delayed retention test performance, controlling for group (Bacelar et al., 2020; Bacelar, Parma, Cabral et al., 2022; Grand et al., 2017; Leiker et al., 2016; Leiker et al., 2019; Parma et al., 2023; Ste-Marie et al., 2013; Barros et al., 2019), with only one of them (Bacelar, Parma, Cabral et al., 2022) finding a significant effect in the expected direction (i.e., controlling for group, participants with higher levels of motivation learned better). This type of analysis is critical because it shows the unique contribution of motivation to explaining the variance observed in the learning effect. In light of these results and the limited data, we encourage future studies on the topic to conduct inferential analyses to test causal relationships between mechanistic and behavioral variables of interest.

In summary, our main research findings can be translated into the following implications for current and future research targeting OPTIMAL theory predictions and beyond. Regarding the former, we simply do not have evidence that manipulations associated with the motivational branch of OPTIMAL theory are indeed motivating. This finding is driven, in part, by the lack of experiments measuring motivation. Important to note, this can be partially explained by the fact that some experiments may not have been designed to target this construct in the first place (e.g., Steel et al., 2016). Regardless of the focus of the research, however, from a methodological standpoint, it is crucial that researchers more consistently engage in the measurement of the constructs/mechanisms they are intending to affect. For researchers interested in evaluating OPTIMAL theory predictions, we recommend the assessments of whether experimental conditions that are designed to enhance expectancies or support autonomy increase motivation and if motivation mediates potential learning effects. This step is crucial in determining the mechanistic role played by motivation in motor learning and to unravel or rule out mechanisms underlying the behavioral effects associated with autonomy support and enhanced expectancies. Although frequently recognized as a key factor in the motor learning process, the very few studies that conducted inferential analyses on the relationship between motivation and learning suggest that this association is yet to be established.

Author Contributions (CRediT Taxonomy):

Conceptualization: JOP, MWM, MFBB

Data curation: JOP, MFBB

Formal analysis: JOP, MFBB

Investigation: JOP, MFBB

Methodology: JOP, MFBB

Project administration: JOP, MWM, MFBB

Software: MFBB

Supervision: MFBB

Validation: JOP, MFBB

Visualization: JOP, MFBB

Writing – original draft: JOP, MFBB

Writing – review & editing: JOP, MWM, MFBB

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