Rev. Psicol. (Arequipa. Univ. Catól. San Pablo) / Año 2025 / Vol 15 / N° 1 / pp. 41-55
ISSN 2306-0565 versión impresa / ISSN 2311-7397 versión on line

Smartphone Technology for Reporting Errors in Error Management Contexts

Tecnología de Teléfonos Inteligentes para Reportar Errores
en Contextos de Gestión del Error

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Abstract
Whereas error prevention in organizations recurs to diverse ways of ensuring that worker behavior complies with norms, rules, and procedures and to elimination of the precursors of error (ineffective layout, inadequate task demands, weak training), error management accepts error as unavoidable and emphasizes its positive administration. The error management sequence starts with the detection of error and follows with its reporting, identification of causes, correction, and institutionalization of the correction. However, error management lags behind error prevention in use of tools of the digitalization/automation era. We developed an application for worker's use of his/her smartphone to report errors —SOLUCIONA— in error management. Before disseminating it, workers of six plants of a Peruvian gas bottling company received training to improve worker empowerment in error reporting as part of company strategy. Then, workers of three plants were trained to use SOLUCIONA whereas workers of three other plants maintained use of pencil and paper. The experimental design took into account the latitude and altitude of the plants' locations in the Peruvian territory. We obtained pretest and posttest measurements which included an

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adaptation of Rybowiak et al. (1999)'s Error Orientation Questionnaire. Experimental group workers —exposed to SOLUCIONA— quintupled the frequency of error reporting compared to control workers and experimental managers significantly increased their frequency of solutions. The technological intervention did not impair worker empowerment; rather, it brought advantages in subjective competence and learning from errors. We conclude that smartphone technology improves error management without adverse effects.

Keywords: Error management, smartphone technology, error reporting, error solution, Error Orientation Questionnaire.

Resumen

Mientras que la prevención de errores en las organizaciones recurre a diversas maneras de garantizar que el comportamiento de los trabajadores cumpla con las normas, reglas y procedimientos, y de eliminar las causas que los provocan (disposición ineficaz, exigencias de tareas inadecuadas, capacitación deficiente), la gestión de errores los acepta como inevitables y prioriza su gestión positiva. La secuencia de la gestión de errores comienza con la detección del error y continúa con su reporte, la identificación de las causas, la corrección y la institucionalización de la corrección. Sin embargo, la gestión de errores va a la zaga de la prevención en el uso de las herramientas de la era de la digitalización/automatización. Desarrollamos una aplicación para que los trabajadores usen sus teléfonos inteligentes para reportar errores —SOLUCIONA— en la gestión de errores. Antes de su difusión, los trabajadores de seis plantas de una empresa peruana de envasado de gas recibieron capacitación para mejorar su empoderamiento en el reporte de errores como parte de la estrategia de la empresa. Posteriormente, se capacitó a los trabajadores de tres plantas en el uso de SOLUCIONA, mientras que los de otras tres plantas mantuvieron el uso de lápiz y papel. El diseño experimental tuvo en cuenta la latitud y la altitud de las plantas en el territorio peruano. Se obtuvieron mediciones pretest y postest, que incluyeron una adaptación del Cuestionario de Orientación al Error de Rybowiak et al. (1999). Los trabajadores del grupo experimental expuestos a SOLUCIONA quintuplicaron la frecuencia de reporte de errores en comparación con los trabajadores de control, y los gerentes experimentales aumentaron significativamente la frecuencia de soluciones. La intervención tecnológica no perjudicó el empoderamiento de los trabajadores; más bien, aportó ventajas en la competencia subjetiva y el aprendizaje a partir de los errores. Concluimos que la tecnología de teléfonos inteligentes mejora la gestión de errores sin efectos adversos.

Palabras clave: Gestión del error, gerencia, tecnología smartphone, reporte de error, solución de error, Cuestionario de Orientación de Errores.

Introduction

Human error occurs in every work setting —construction, health care, hospitality, manufacturing, outsourced services, transportation, etc.— and has costs (e.g., Walsh et al., 2017). Errors are unintended deviations from plans, goals, or adequate processing of feedback or incorrect actions due to lack of knowledge (Frese & Keith, 2015; Frese & Zapf, 1994; Reason, 1990; van Dyck et al., 2005). Errors are differentiated from inefficiencies (costlier ways of doing things), violations (intended errors), failures (uncorrected errors), and risks (which reside in the environment, not in the person-environment interaction) (Frese & Keith, 2015). In turn, individual errors are distinguished from errors influenced by the organization, such as those originating in organizational rules or standards or those which cause a cascade of other errors if they are not corrected and remain latent (Frese & Keith, 2015).

Error prevention, a primary interest of engineers in the safety area, recurs to diverse ways of ensuring that worker behavior complies with norms, rules, and procedures and to elimination of the precursors of error (ineffective layout, task demands, weak training, etc.) to eradicate error (e.g., Hale, 2003; Reason, 2000). In contrast, error management (EM), an interest of psychologists, accepts error as unavoidable and emphasizes its positive administration in all work areas. Thus, EM seeks to bring specific errors to the surface and correct them at their roots, avoiding their negative consequences and rapidly containing damage. Van Dyck et al. (2005) measured organizational norms and practices involving error detection, communication, and correction in various European countries and demonstrated that the culture of EM correlated positively with organizational effectiveness. Such results have been replicated in other continents (e.g., Guchait et al., 2020) and research has targeted also more specific outcomes (e.g., Afsar et al., 2017; Fay & Frese 2001; Putz et al., 2012; Rybowiak et al., 1999; Scheel & Hausmann 2013) and has addressed likely moderators (e.g., Buntzen & Hinrichs, 2021; Göktürk et al., 2017).

Since error detection is regarded as the most important part of EM, its process and strengthening have received significant research attention (e.g., Bell & Koslowski, 2011; Dahlin et al., 2005; Dörner, 1996; Edmonson & Lei, 2014; Falkestein et al., 2000; Frese & Keith, 2015; Frese & Zapf, 2004; Hofmann & Frese, 2011b; Kanki et al., 2010; Madsen & Desai, 2010; Milanovich et al., 1998; Rabbitt, 1978: Reason, 1990; Shimizu & Hitt, 2011; Thomas, 2004; Tjosvold et al., 2004; Van Dyck et al., 2005). Yet, detected errors are useless if they are not reported. EM research has addressed error reporting mainly as a motivational challenge under the assumption that people need to be at ease to report errors; thus, most of the studies have sought to identify and counteract organizational and personal sources of inhibition to report (e.g., Bell & Kozlowski, 2008; Carmeli & Gittell, 2009; Fehr et al., 2010; Frese & Keith, 2015; Heimbeck et al., 2006; Keith & Frese, 2005; Kim et al., 2004; Lee et al., 2004; Nembhard & Edmondson, 2012; Rybowiak et al., 1999; Sheperd et al., 2011; Utz et al., 2009; van Dyck et al., 2005; Zhao, 2011; Zhao & Olivera, 2006).

In this context, EM generally obtains error reports through oral or written individual submission or group qualitative reporting whose formats have lacked innovation in the past three decades. In contrast, error prevention has recurred to computerized means to improve error reporting. For example, the Johns Hopkins Children's Center installed a voluntary online medication error reporting system. "The system was accessed via any and all public workstation computers on every clinical floor in the institution. (...) Any provider (nurse, pharmacist, physician, therapist) was able to enter a report by accessing this website and completing a short form with predetermined error type choices in four categories" (Miller et al., 2006, p. 209). The tool was effective as a way of collecting reliable information on errors in real time. Nevertheless, this type of technological innovation has not occurred in the context of EM. Thus, the Miller et al. (2006) study was not considered in the Frese and Keith (2015) *Annual Review of Psychology* chapter. The study described here was designed to test whether the introduction of a novel practice —individual worker's use of his/her smartphone for error reporting into a data set— benefits EM. The use of smartphones to report error can be regarded as consistent with the "always on" culture that prevails at work milieus (McDowall & Kinman, 2017) and has been shown to improve reporting of work-related activities in diverse professional and work settings (e.g., van de Pol et al., 2019). We tested

Hypothesis 1. Smartphone technology increases error reporting.

The EM process assumedly flows through a series of phases: detecting, reporting, analyzing, finding causes, and preventing the re-occurrence of error (Frese & Keith, 2015). Yet, these phases have not been clearly distinguished in EM research. Virtually all the studies have been concerned either with the detection of error or with the other phases undistinguished from each other. Thus, the relationship between error reporting and the solution of error has not been empirically addressed. Whereas error solution has typically been treated as a task carried out by a working team, the literature indicates a need for stimulating managers to provide solutions in response to error reporting (Cunningham & Geller, 2011). Letting the worker deal alone with error as an organizational issue, without the participation of supervisors or managers, might bias the EM system toward the correction of some types of errors and downplaying of others (see Horvath et al., 2021). The participation of supervisors or managers appears to be necessary to round up the process of EM ensuring systemic solutions when necessary. We tested

Hypothesis 2. Smartphone technology increases managers' error solutions.

On the other hand, it has been shown that information and communication technology demands generate positive and negative worker outcomes (Stich et al., 2015). Since there was a risk that smartphone technology could impair worker empowerment, we tested:

Hypothesis 3. Smartphone technology impairs competency in dealing with error, learning from error, assumption of risks, handling of the stress associated with error, anticipation of error, and occultation of error.

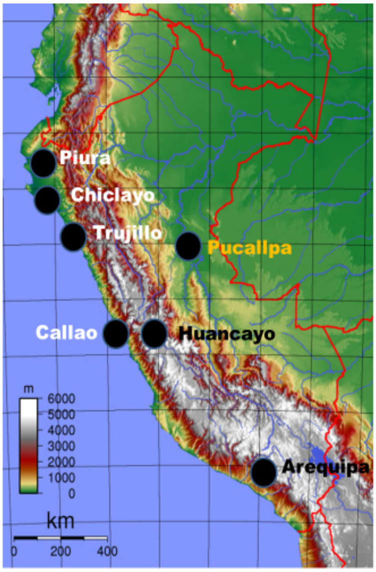
Method

A quasi-experiment (Shadish & Cook, 2009) was designed and carried out in Peru, whose aboriginal population, rooted in Eurasian/Mongol admixture, migrated from near Lake Baikal 20,000 years ago (Yu et al., 2020) and admixed with Spaniard invaders in the 16th century and thereafter. Peru is a mid-income country who presents the highest rate of entrepreneurship in the world and differs from Europeans by being more collectivistic than individualistic, although being male, older, and living in Lima, the capital city, apparently increases individualism (León & García-Saavedra, 2020).

Organizational setting

A 70 years old gas-bottling company which has belonged to international conglomerates since 1993 was targeted for the research. The company had a 25% share of the Peruvian market of gas distribution. It employed about 350 workers in its bottling plants in seven cities. Prior to our EM intervention, the company employed an error prevention model.

Figure 1.
Geographic location of the gas bottling plants



Research design

A smartphone experimental condition was implemented in three plants after the pretest (experimental group) whereas a paper-and-pencil reporting format was implemented in other three plants (control group) and in the pretest of the experimental group. Fig. 1 exhibits the location of the plants. Latitude and altitude needed control because proximity to the equator (León & Burga-León, 2014) and altitude above sea level (León & Avilés, 2016) impair cognitive performance in Peru. Every 1000 m. of altitude are calculated to add 10% to UV radiation; UV photons are more abundant at high altitude due to the thinning of the ozone layer in the high atmosphere. UV radiation, which is stronger near the equator, impairs cognitive functioning (León, 2018). The Pucallpa plant, in the Amazon forest, was excluded because it lacked a comparison plant; the Amazon region differs from the remainder of the country in important respects, including cognitive performance (León & Avilés, 2016; León & Burga-León, 2014). The experimental group encompassed Piura (coast), Trujillo (coast), and Arequipa (high altitude) whereas the control group encompassed Chiclayo (coast), Callao (coast), and Huancayo (high altitude). The interventions occurred in November 2017. Table 1 summarizes the research design and its implementation.

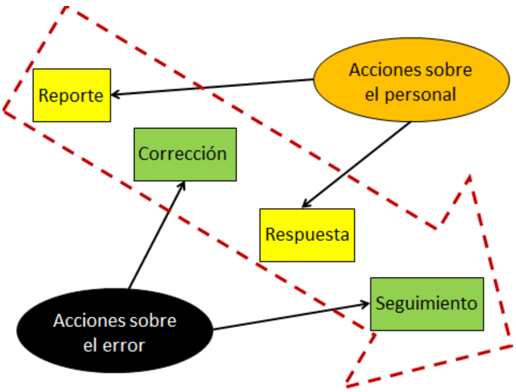
Table 1.
Design of the quasi-experiment

Group	Preparation	Pretest (3 months)	Intervention	Posttest (3 months)
Experimental	Training of plant managers in EM culture and utilization of *Soluciona* to provide solutions	Workers respond to Error Orientation Questionnaire at Day 1 of pretest and are instructed to report errors using paper and pencil. Clerk digitalizes data into *Soluciona*.	EM culture talks for workers. Worker training in imputing errors into *Soluciona* using smartphone	Workers report error using *Soluciona*. Workers respond to Error Orientation Questionnaire at the last day of the posttest.
Control	Training of plant managers in EM culture and utilization of *Soluciona* to provide solutions	Workers respond to Error Orientation Questionnaire at Day 1 of pretest and are instructed to report errors using paper and pencil. Clerk digitalizes data into *Soluciona*.	EM culture talks for workers.	Workers report errors using paper and pencil. Clerk digitalizes data into *Soluciona*. Workers respond to Error Orientation Questionnaire at the last day of the posttest.

Intervention

The company's Operations Manager instructed plant managers about the quasi-experiment prior to initiating activities.

EM culture: detecting and reporting errors. Workers were told that error can be detected through recognition of a specific error, suspicion of error, or standard checking. That the worker should report a detected error regardless of whether it was simple or complex, recognized during an action or as a result of a cycle of actions, attributable to oneself or to others, early or late, and whether the individual or the group was the discoverer. The worker would have to have a sense of urgency; the later the discovery of error, the worse its consequences (Reason, 1990). Worker attention to the company's safety and general work standards would help him/her to detect errors as deviations from the standards. The relationship between occurrence of errors and company's economic losses was explained and workers were induced to worry only moderately about failing (Weick, Sutcliffe, & Obstfeld, 1999). Special emphasis was put in assuring workers that error reporting would not generate negative consequences for them (Edmonson & Lei, 2014; Nembhard & Edmondson, 2014; Zhao & Olivera, 2006). The expectation of negative consequences is a cause of negation and displacement of guilt, which were special risks considering the rigid organizational hierarchy (Shimizu & Hitt, 2011) and staff heterogeneity (Dahlin, Weingart, & Hinds, 2005) of the company. Worker's distancing from any perfectionism that could make him/her seeing error as catastrophic was recommended, as well as minimization of negative reactions of the work environment toward error reporting (Ellis & Ellis, 2014). To this end, the managers remarked that an error is not a violation (Kim *et al*., 2004) and they themselves started to pay attention to the cognitive, emotional, and motivational aspects involved in organizational change (Van Dyck et al., 2010). Workers were instructed to control the emotions that normally follow the detection of own errors and their reporting (Bell & Kozlowski, 2008; Keith & Frese, 2005) and were also induced to see error reporting as an opportunity of personal development (Mangels et al., 2006). Finally, the managers remarked the positive aspects of the organizational learning that would result from error reporting (Rybowiak et al., 1999).



EM culture: acting upon errors. Plant managers were required to implement damage control to reduce the negative consequences of error once it was identified and to consult with workers as necessary in this process. If the case was one of an error cascade, in which one error leads to others (Goodman et al., 2011), greater benefits would be derived from damage control. A methodology was established to investigate direct causes, preconditions, and latent failures; this included the Swiss cheese, bowtie, and other techniques (Reason, 1990) and, in some instances, encompassed an evaluation of the cost/benefit of the corrections (Morrison & Phelps, 1999). The institutionalization of the correction was emphasized to plant managers as a way of avoiding the repetition of error and they were advised to seek solutions not as an obligation but to generate benefits. They were also reminded that actions implicating changes in the *status quo* or procedures carried out since long time ago in the same manner could generate resistance among workers. But, if the worker was not willing to change, he/she would continue committing the same errors (Zhao & Olivera, 2006). Plant managers would have to monitor the implementation of corrections and implement procedures of error follow-up through periodic evaluations capable of generating alerts. Finally, they would have to seek equilibrium between perfection and risk; a too perfect system could make business unprofitable.

Smartphone technology. An application christened SOLUCIONA was developed for use in the worker's smartphone allowing him/her to report errors which were automatically registered in an Excel data set. The system was able to receive a narrative description and asked the worker to classify the error along three dimensions. The plant manager was alerted of any entry, was able to access the system at any time, and was expected to search for causes of the error, alone or helped by others, and identify a solution. Then, he would successively enter a description of the solution, a declaration that the error was solved, and a personnel alert about the case.

Study subjects

Since responding to Rybowiak et al. (1999)'s Error Orientation Questionnaire (EOQ) was voluntary, workers in practice self-selected themselves as they accepted to participate in this aspect of the study. The rate of participation was 43% (pretest) and 45% (posttest) in the control group and 56% and 59%, respectively, in the experimental group. On the other hand, worker participation in training on worker empowerment and SOLUCIONA was obligatory.

Measurements

Error reports. During the pretest of both the experimental and control groups and during the posttest of the control group, workers reported errors using a paper-and-pencil format that contained the same response categories used in the smartphone application. These reports were digitalized into the SOLUCIONA data set by a clerk. The posttest reports of the experimental group went directly into the data set through the smartphones of the workers'. Therefore, every member of the six plants in the study (N = 277) had a registry in SOLUCIONA.

Error solutions. Plant managers in the control group, too, were asked to address the errors in SOLUCIONA until a solution was found. Therefore, the solutions of managers in the control and experimental groups at pretest and posttest followed a uniform procedure.

Error orientation. The first version of Rybowiak et al.'s (1999) Error Orientation Questionnaire (EOQ), validated in a German sample, measured the following constructs:

> (1) Error competence is active knowledge for immediate recovery from errors and reduction in error consequences.... (2) Learning from errors is the ability to prevent errors in the long term by learning from them, planning, and changing work processes... (3) Error risk taking is the result of an achievement-oriented attitude which requires flexibility and taking responsibility... (4) Error strain is characterized by a generalized fear of committing errors and by negative emotional reactions... (5) Error anticipation is pessimistic and negatively tuned but at the same time it may be a realistic orientation... (6) Covering up errors is mainly the strategy of a non-self-assured person and may also be an adaptation to error-sensitive conditions at work, for example, job uncertainty. (pp. 542-543)

The first three constructs were measured by four items and the last three constructs, by five items. A second version of the questionnaire, validated in the Netherlands, added two constructs: communicating error (four items) and thinking about error (five items). We made a forward-back Spanish translation of the 36-item questionnaire.

This research complied with the American Psychological Association Code of Ethics, with the Helsinki Declaration, and with Peruvian legislation on the topic.

Results

Effects on error reporting and solution

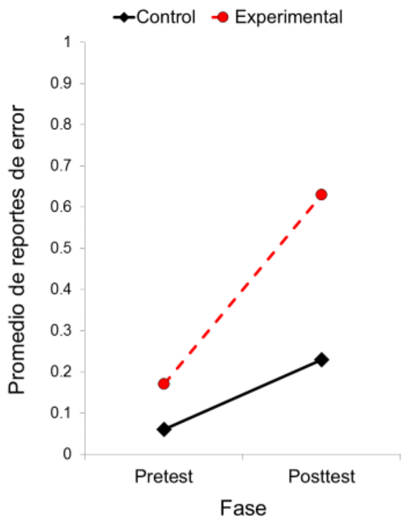
Error reporting. Since very few workers reported more than one error at the posttest, a dichotomy was utilized to evaluate the effects of the intervention on error reporting (reporting= 1, not reporting= 0). Since we were not interested in the effects of the intervention designed to strengthen the culture of EM, the most parsimonious way of evaluating the smartphone intervention required the use of a *generalized* linear model with a focus on the treatment (control, experimental) x phase (pretest, posttest) interaction; there are antecedents of ignoring main effects in the literature (e.g., León et al., 2011).

Table 2.
Results of generalized linear model entailing frequency of error reporting (yes, no) which excluded main effects (N= 564)

Treatment and phase	Wald's χ2	Degrees of freedom	*p*	Exp(B)	95% confidence interval
Experimental, Posttest				1.000	
Control, Posttest	40.834	1	.001	0.178	[0.105, 0.302]
Experimental, Pretest	40.839	1	.001	0.117	[0.061, 0.226]
Control, Pretest	75.263	1	.001	0.036	[0.017, 0.076]

Table 2 shows that error reporting was at least five times greater at the post-test in the experimental group than in any of the other conditions according to the respective *odds ratios* [Exp(B)]. The curves in Figure 2 suggest positive effects of the strengthened culture of EM on error reporting in both experimental and control groups.

Figure 2.
Estimated means of error reporting according to treatment condition and phase of data collection from generalized linear model (N= 271)



Note: We recurred to bootstrapping using 1000 samples.

Error solutions. At the pretest, plant managers provided 22 solutions in the control group and 23 solutions in the experimental group. At the posttest, the frequencies were, respectively, 22 and 89. That is, whereas managers in the control group did not modify their rate of error solutions, managers in the experimental group significantly increased it ($\chi 2$ = 115.62, df = 3, p = .000).

Effects on worker empowerment

Since Rybowiak et al. (1999)'s Error Orientation Questionnaire needed calibration in Peru, we performed three confirmatory correlated-factor analyses using aggregated pretest and posttest data (N = 271). Rybowiak et al. (1999)'s six-factor German model did not satisfy Schreiber et al.'s (2006) model-fit requirements of a $\chi 2/df < 2$ or 3 and the lesser the ECVI the better nor Bagozzi and Yi's (2012) criteria that "given SRMR ≤ .07, a model might be satisfactory with RMSEA ≤ .07, NNFI [Tucker-Lewis Index] ≥ .92, and CFI ≥ .93." The eight-factor Dutch model presented an expected cross-validation index less adequate than the German model. Elimination of EOQ items 4, 17, 21, 25, and 28 produced a six-factor Peruvian model which outperformed those of the German and Dutch models in each evaluative dimension: 1.75 versus 2.25 and 1.98 in $\chi 2/df$; 0.93 versus 0.85 and 0.85 in CFI; 0.86 versus .80 and .78 in AGFI; 0.60 versus 0.71 and 0.67 in SRMR; 0.53 versus 0.68 and 0.60 in RMSEA; and 1.85 versus 3.32 and 5.16 in ECVI. Following Peters' (2014) recommendation, we calculated the reliability of each sum of items per factor of the Peruvian model using *omega*, which is more precise than the traditional *alpha*. *Alpha* ranged from .66 to .89 in the pretest and from .71 to .86 in the posttest; *omega* ranged from .63 to .73 in the pretest and from .63 to .80 in the posttest.

Table 3.

Results of univariate general lineal models with a factorial design excluding main effects to evaluate impacts of the SOLUCIONA intervention on each EOQ summated score

Treatment groups and statistical indicators	Summated scores					
	Competence	Learning	Risk	Strain	Anticipation	Cover-up
Control pretest						
Mean	3.99	3.96	3.01	2.40	2.11	2.25
Standard error	.095	.112	.141	.108	.095	.115
95% CI	3.77; 4.18	3.74; 4.17	2.71; 3.31	2.17; 2.60	1.93; 2.29	2.02; 2.51
p	.111	.109	.049	.973	.142	.015
Control postest						
Mean	3.76	3.86	2.60	2.31	2.18	1.82
Standard error	.107	.109	.128	.103	.101	.090
95% CI	3.55; 3.98	3.64; 4.07	2.39; 2.84	2.09; 2.51	1.99; 2.38	1.64; 1.98
p	.001	.027	.867	.549	.384	.712
Experimental pretest						
Mean	3.99	3.82	2.55	2.31	2.10	2.13
Standard error	.081	.106	.109	.114	.091	.141
95% CI	3.82; 4.13	3.61; 4.00	2.35; 2.58	2.08; 2.54	1.92; 2.28	1.87; 2.42
p	.072	.011	.583	.589	.091	.144
Experimental postest						
Mean	4.19	4.20	2.64	2.39	2.31	1.87
Standard error	.076	.100	.128	.101	.098	.102
95% CI	4.04; 4.34	3.99; 4.39	2.39; 2.90	2.21; 2.59	2.12; 2.49	1.69; 2.97
p	.001	.001	.001	.001	.001	.001

Notes: The experimental posttest is the reference for the ps of the other groups and, in turn, exhibits the p corresponding to the intercept. All the standard errors, confidence intervals, and probabilities are bootstrapped with 1000 samples (N = 271).

Whereas workers' error reports at pretest and posttest were linked in the SOLUCIONA data set, their questionnaire responses were not, due to the anonymity offered to respondents. Since the questionnaire data demanded a different statistical treatment, we performed univariate *general* lineal models for the six summated item scores corresponding to the Peruvian factors. It can be seen in Table 3 that the smartphone intervention was associated with improvements in competence and learning that approached statistical significance, whereas worker empowerment in the other areas did not present relevant changes.

Discussion

The study was far from perfect. The rate of participation of workers responding to the EOQ was 45% on average in the control group and 57% in the experimental group. Nonetheless, working with pretest and posttest data allowed us to control for such differences; utilization of the control group with pretest and posttest quasi-experimental design brings a clear advantage in field experiments (Shadish & Cook, 2009). Moreover, the experimental group outperformed the control group in gains in frequency of reporting error and frequency of error solutions from pretest to posttest despite that we attempted to strengthen the culture of EM in both groups simultaneously with the smartphone intervention in the experimental group and apparently succeeded at it. Both groups seemingly improved their frequency of reporting error, but the experimental group did it at a greater rate. Adding confidence in the study outcomes based on SOLUCIONA data, the EOQ yielded improved self-perceived competence in dealing with error and learning from it that approached statistical significance. Therefore, we avoided the extended problem of common-method variance in behavioral research (Podsakoff et al., 2003).

EM can benefit from the use of tools of the digitalization/automation era to improve the frequency of error reporting by workers and error solution by managers with no apparent adverse effects. Since SOLUCIONA can be easily adapted to the specific needs of particular organizational settings, it can be regarded as a practical contribution to EM practices. However, two limitations of the study should be noted. Our technological intervention did not improve risk assumption, error stress, error anticipation, and covering-up error. And a possible weakness of the study posttest was its limited duration (three months), which impeded us to arrive at conclusion regarding a possible Hawthorne effect, that is, worker reactions to the novelty of the task and attention received. Future replications of the present study could pay attention to this problem using a longer pretest and monitoring the curves of monthly reporting and solution of errors.

Financing

This research received no grant for any funding agency in the public, commercial, or not-for-profit sectors.

Conflicts of interest

The authors declare that there is no conflict of interest.

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