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Improving the Measurement of Older Adults' Mobile Device Proficiency: Results and Implications from a Study of Older Adult Smartphone Users

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ABSTRACT Mobile device (e.g., smartphone) proficiency is becoming increasingly necessary to perform important everyday tasks, and inadequate proficiency can prevent groups of individuals such as older adults from obtaining the benefits of mobile computing and smartphone utilization. To facilitate mobile device training and research on barriers to mobile device use and adoption by older adults, Roque and Boot [1] developed the Mobile Device Proficiency Questionnaire (MDPQ). The current study is the first to assess the validity of the MDPQ based on confirmatory factor analysis and objective measures of their smartphone skills. In addition, it represents the first attempt to validate the MDPQ on a sample of older smartphone users. Results suggest that modifications may be necessary for the MDPQ to serve as a valid and reliable measure of proficiency among older adult smartphone users. In this sense, four important implications and recommendations for application of the MDPQ are discussed that could promote the general goal of ensuring that individuals of all ages can benefit from the use of smartphone devices and services such as mobile apps.

INDEX TERMS Social implications of technology, human-computer interaction, cellular phones, construct validity, criterion validity, mobile device proficiency questionnaire, older adults, scale development.

I. INTRODUCTION

Digital skills are becoming increasingly necessary to perform important everyday tasks. Tellingly, in various models of digital divide, scholars have proposed them as one of dimensions of digital inequalities that are vital for attaining beneficial personal and social outcomes [2], [3]. With the expanding prominence of mobile computing a distinct set of abilities referred to as mobile device proficiency has emerged that allow individuals to effectively cope with ubiquitous services such as mobile apps [4]. A lack of mobile device proficiency can prevent individuals from benefiting from the many advantages offered by mobile computing related to communication, navigation, transportation, entertainment, and health [5]. For example, mobile apps allow individuals to communicate with distant friends and family, find their way in unfamiliar cities, pay for street parking, manage chronic conditions, and track their physical activity. Moreover, for a growing number of individuals a smartphone is the only means to access the Internet. While 13% of Americans were smartphone-only users in 2015, this percentage increased to 17% in 2019 [6]. Under the circumstances of smartphone dependence low-proficient individuals will face challenges obtaining these and a myriad of other benefits offered by smart devices and become digitally excluded [5], [7], [8].

Unfortunately, there exists a substantial age-related gap with respect to mobile device experience and proficiency [9]. In the U.S., only 53% of adults aged 65+ own a smartphone, compared to 96% of adults aged 18-29 [6]. Older adult smartphone owners use them to accomplish fewer tasks compared to younger adults [10], and report greater difficulty using smartphones [1] which is caused by their limited resources in terms of cognitive, perceptual and/or motoric abilities [11], [12]. In addition, lower rates of technology adoption,

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use, and proficiency by older adults are linked to a number of other factors, including a lack of technology experience and supportive learning environment, poor technology design, as well as motivational and attitudinal barriers [7], [13]–[15].

These trends in technology proficiency are especially unfortunate as technology has the potential to counter some of the effects of age-related changes, and support the ability of older adults to live independently [16]. For example, changes in vision and cognition cause some older adults to cease driving, and driving cessation is associated with a host of negative health consequences [17]. Ride-sharing apps have the potential to offer a convenient alternative mode of transportation. Technology can also provide social support to older adults by allowing them to communicate with friends and family and to access useful local and national resources on aging. Most (67%) older adults take three or more prescription drugs [18], making medication management challenging. Smartphone medication management apps hold promise with respect to helping individuals with this task [19]. Likewise, smartphone rehabilitation apps were shown to be promising for delivering therapeutic treatment to (older) patients, improving not only their health conditions but also other aspects of quality of life [20]. While technology proficiency benefits all, the benefits to older adults may be especially great [9], [21].

II. BACKGROUND

It would be advantageous to be able to quickly and easily assess an individual's level of mobile device proficiency, especially for older adults who are more variable in their skills, and who might benefit most from innovative services. Advanced knowledge of an older adults' proficiency would be useful for the purpose of technology training to allow training to start at the appropriate level and target an individual's weakest skills. In the context of training a new medication management app, instruction on how to turn a smartphone on and off would be of little use, and frustrating to receive, for a proficient older adult. Conversely, this same instruction might be vital to the success of an older adult with minimal proficiency.

Quick measures of proficiency also have the potential to be useful in organizing group training sessions, a format common to many community centers, retirement communities, and assisted living facilities. Training sessions comprised of individuals of disparate proficiency can cause frustration when the presented material is too basic for individuals with advanced proficiency, and too complex for individuals with low proficiency [22]. Finally, quick, easy, reliable, and valid measures of digital skills and proficiency have the potential to advance conceptual models of technology acceptance by allowing large datasets to be collected on proficiency, along with other measures, to understand facilitators of, and barriers to, technology proficiency [4], [23].

Roque and Boot [1] developed the Mobile Device Proficiency Questionnaire (MDPQ) for exactly these research and training purposes. The development of the MDPQ was deemed necessary due to the rise in dominance of mobile computing, the unique benefits of mobile computing in comparison to desktop computing, and the unique input and design issues (e.g., smaller screens, touchscreen input) associated with mobile computing that can influence tablet and smartphone proficiency. In addition, prior research has proposed measures of mobile phone proficiency that are part of general inventories for assessing digital skills. For instance, in the recently proposed short form of the Internet Skills Scale, mobile skills are measured with only three items, representing one dimension of Internet skills [4]. Thus, they might not be able to capture the complexity and multidimensionality of smartphone-related skills.

The MDPQ is a measure[1] that presents 46 items divided across eight subscales (see Table 7 in the Appendix): Mobile Device Basics; Communication; Data and File Storage; Internet; Calendar; Entertainment; Privacy; and Troubleshooting and Software Management.[2] The questionnaire asks respondents to answer prompts on a five-point scale: "1 = never tried", "2 = not at all", "3 = not very easily", "4 = somewhat easily", and "5 = very easily". Prompts and response options are arranged in a matrix format to facilitate quick and easy responding. Principal Components Analysis (PCA) was used to reduce this larger scale into a brief measure, the MDPQ-16, with two questions per subscale [1]. To score the MDPQ-46 and MDPQ-16, responses to the questions of each subscale are averaged, and then these averages are summed for a total score between eight and 40. This means that an individual's MDPQ score is partly dependent on the suggested allocation of items to sub-scales. Further, it means that in the context of the scoring system all sub-scales contribute equally to the final MDPQ score.

To validate the MDPQ-46 and MDPQ-16, Roque and Boot [1] collected data from a sample ($N = 149$) of younger and older adults. Reflecting the digital divide, younger adults scored significantly higher than older adults, and even among the older adult group (age 65+) greater age was associated with lower proficiency. Scores were more correlated with participants' length and frequency of mobile device use, and less correlated with their length and frequency of computer use, consistent with the scale having divergent validity. With respect to reliability, Cronbach's α for the MDPQ-46, MDPQ-16, and all subscales ranged from .75 to .99. PCA revealed a factor structure that roughly mirrored the MDPQ-46 subscales, with exception that there were six factors identified rather than eight.

Although this initial exploration suggested the MDPQ-46 as a reliable and valid method to accurately assess mobile device proficiency, a number of important questions remain unanswered, and should be answered before the wide scale deployment of the MDPQ for research and training purposes.

[1]Throughout this paper the (generic) term "measure" is used to refer to a multi-item operationalization of a construct, whereas the term "scale" is used when we refer to measures comprised of reflective items [48]. The terms "prompts", "items" and "indicators" are used interchangeably.

[2]Hereafter we refer to the full MDPQ as the MDPQ-46 to distinct it from other (short) forms of the MDPQ.

The MDPQ-46 is a measure of proficiency based on self-report. The extent to which the MDPQ-46 matches objective proficiency, as measured by behavioral criteria such as the speed and accuracy of performing various mobile device tasks, is still unclear. Further, previous validation studies have assessed MDPQ-46 scores within samples of older adults that included individuals with mobile device proficiency, as well as individuals with no experience at all. Heterogeneous samples likely overestimated the utility of the MDPQ-46 in predicting proficiency among older adults with previous mobile device proficiency and older adult smartphone owners, and may have also inflated measures of internal consistency. Finally, Roque and Boot [1] assessed the factor structure of the MDPQ-46 with less sophisticated exploratory methods, and not with appropriate confirmatory factorial methods.

The goal of the presented study was to address these limitations, using a dataset that included both the MDPQ-46 information and objective measures of smartphone performance [20], with a special focus on advancing the understanding of the construct [24] and criterion validity [25]. The aim of this paper is to establish the construct validity of MDPQ-46 with convergent and discriminant validation, as well as to assess criterion validity by comparing self-reported proficiency with an objective measure of proficiency (i.e., task performance metrics collected in usability tests).

Using these and other standard procedures for scale validation [26], a further goal is to refine the MDPQ to boost its reliability and validity, especially among current older smartphone users.

III. METHOD

A. DATA COLLECTION

To consider the construct and criterion validity of the MDPQ-46 in the context of older adults who are smartphone users, the data were collected in 2017 within a summative usability test aimed at comparing the usability of a standard Android (Figure 1) and an age-friendly GoLivePhone (GLP) (Figure 1) smartphone launcher for older adults.[3] The Android operating system was selected because its use was the most prevalent among the target population of participants in Slovenia [27], whereas the selection of GLP was informed by its high-level age-friendly design [28].

In each test session participants were first briefed about the study's goals, signed a consent form, and answered a pre-test questionnaire which included the MDPQ-46. Then, they conducted a series of usability tasks in the lab to assess and compare the usability of the user interface on Android and GLP launcher. Interface order was counterbalanced. In the last part, a questionnaire asked participants about their subjective evaluation of usability and emotional appeal of launchers, and perceived workload during the testing session.[4]

Two quantitative usability measures were recorded in line with the definitions of usability metrics suggested by

FIGURE 1. Home-screens of two smartphone launchers used in usability testing: Android launcher (left) and GoLivePhone launcher (right).

Albert and Tullis [29]. Notably, *task success* was determined as the percentage of participants who successfully completed a task, whereas *task efficiency* was measured as the ratio between the optimal number of screen touches needed to complete a task (i.e., the shortest path to task completion) and the actual number of screen touches made by the participant to complete a task. The two usability metrics were used as the (external) criterion to assess the validity of the MDPQ.

B. SUBJECTS

Due to the difficulty in recruitment of this age group of participants in Slovenia and limited available research resources to generate a random sample, a non-probability purposive sampling procedure was used to recruit 50 older smartphone users (defined as individuals who have used a smartphone in the last 3 months)[5] aged 60+. Smartphone familiarity was a necessary eligibility condition, because only smartphone users were able to participate in usability testing. Drawing on the recommendations for recruitment of older participants in human-computer research and usability tests [30] institutions and organizations working in the field of life-long learning and inter-generational community centers were engaged to attract a number of potential participants who were willing to collaborate and fulfilled eligibility criteria (i.e., age, smartphone experience). Sample characteristics, which closely resemble the structure of the target population according to age, gender, and educational attainment [31], are summarized in Table 1.

C. INSTRUMENTATION

The MDPQ-46 – as originally developed by Roque and Boot [1] – was administered to participants (see also

[3] For details on study design see Petrovčič *et al.* [20].

[4] The post-test data are not reported in this study.

[5] All participants provided written informed consent.

TABLE 1. Sample characteristics.

Variable	Categories	N	%
Gender	Male	17	34
	Female	33	66
Age	61-65	22	44
	66-75	23	46
	76 or more	5	10
Education	Primary school or less	4	8
	Vocational or technical secondary school	13	26
	Secondary school or high school	6	12
	College or more	27	54
Smartphone use frequency	Every day or almost every day	47	94
	At least once a week (but not every day)	2	4
	Less than once a month	1	2
Year of starting using smartphone	This year	4	8
	Last year	7	14
	Two years ago	7	14
	Three years ago	11	22
	Four, five years ago	14	28
	Six years ago or earlier	7	14
Current operating system	Android	44	88
	iOS	3	6
	Windows Phone	1	2
	Other	2	4
Total		50	100

Section II.). The MDPQ-46 was translated into Slovenian language using the TRAPD method [32]. Notably, two independent translations of the MDPQ-46 had been first produced by research team members and later reviewed by a third researcher who also checked any potential translation annotations (e.g., for ambiguous concepts) and compared the reviewed translation with the original questionnaire. Before approving the translation, the reviewed version was also adapted for personal interviewing and translated back to English. The approved translation was then pretested on a small scale pilot study and corrected on the basis of the feedback from the pretest to obtain the final translation.

In contrast with prior validation of the MDPQ-46 [1] which used a self-administered questionnaire (SAQ) to collect response from subjects, computer-assisted personal interviewing (CAPI) was employed for this research. A trained study assistant recorded the answers of participants in computer using a special survey tool *1KA – One click survey*.

D. PROCEDURE AND ANALYSIS

The validation of MDPQ-46 scale consisted of three stages (Figure 2). First, we screened the data on an item level, assessed the internal consistency of subscales, and evaluated the suitability of data for confirmatory factor analysis (CFA) modeling. Next, an adapted version of the scale (i.e., MDPQ-28) was created and examined with CFA to verify the assumed underlying factor structure.

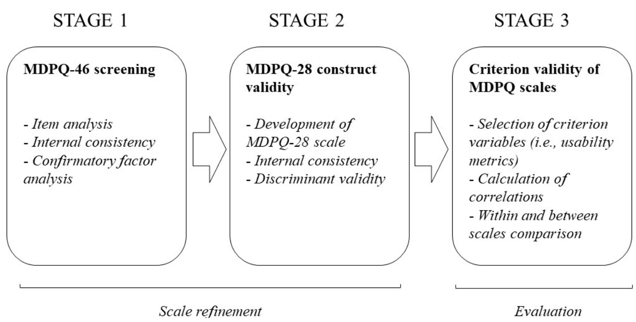

FIGURE 2. The three stages in the validation procedure of Mobile Device Proficiency Questionnaire (MDPQ).

In the second stage, convergent and discriminant validity of subscales were assessed. Convergent validity was assessed by internal consistency coefficient Cronbach's alpha and composite reliability coefficients (CRs). Discriminant validity was assessed by comparison of between factor squared correlations and average variances extracted (AVE) [33]. Next, following Roque and Boot [1], a short form of the MDPQ-28 (i.e., MDPQ-14) was constructed on the basis of CFA factor loadings.

In the third stage, both original and adapted MDPQ scales were subjected to the assessment of criterion validity [34] based on Pearson's correlation coefficients between the three MDPQ scores and external criteria, i.e., metrics derived from usability testing. Differences in correlation estimates within and between three MDPQ scores and different usability metrics were assessed by statistical tests for comparing two dependent correlations with one variable in common [35]. The analyses were run in IBM SPSS Statistics 24 [36] and IBM SPSS Amos 24 [37].

IV. RESULTS

A. EVALUATION OF MDPQ-46

Data screening based on descriptive statistics indicated that a number of items in the MDPQ-46 had very low variability within this sample of smartphone users. The most extreme were "Turn the device on and off" and "Charge the device when the battery is low", where 98% and 94% of respondents have chosen the same answer (Table 7 in the Appendix). The internal consistency measure Cronbach's alpha (α) yielded acceptable estimates for Mobile device basics ($\alpha = .678$), Communication ($\alpha = .846$), Data and file storage ($\alpha = .696$), Internet ($\alpha = .897$), Calendar ($\alpha = .885$), and Troubleshooting and Software Management ($\alpha = .808$), whereas unacceptable internal consistency was found for subscales Privacy (α = .415) and Entertainment (α = .567). Moreover, CFA on MDPQ-46 yielded an improper factorial solution (i.e., non-positive definite model-implied covariance matrix); the problem persisted even when items with low variability were excluded from the model.

B. DEVELOPMENT OF MDPQ-28

In the adapted MDPQ-46 we have excluded 18 items from the initial pool of items (Table 7 in Appendix) with the proposed factor structure (i.e., allocation of each item into the corresponding factor) being preserved as specified in the MDPQ-46. Two items were deleted due to lack of variability, 12 items due to low magnitude of factor loading on the corresponding factor, and four items due to elimination of the subscale Privacy which had an unacceptable value for internal consistency (α = .415). In addition, the measurement model based on CFA that included the factor Privacy yielded a non-positive definite model-implied covariance matrix, indicating factor misspecification. The refinement process resulted in an adapted version of the original scale (i.e., MDPQ-28) that contained seven sub-scales and 28 items (Table 2). The resulting seven-factor, CFA model's fit (χ^2 = 431, df = 329; RMSEA = .079; SRMR = .077; CFI = .894) was satisfactory [38]. In addition, construct (composite) reliability calculations also revealed acceptable to high internal consistency for all seven subscales, ranging from α = .650 for Entertainment to α = .926 for Communication.

Discriminant validity of the MDPQ-28 was assessed by comparison of squared correlation and AVE's for each pair of constructs. For every pair of constructs, A and B, the AVE for A and the AVE for B both need to be larger than the shared variance (i.e., square of the correlation) between A and B [33]. Such criterion was not met for the following five pairs of factors (Table 3): Internet and Data and file storage, Entertainment and Troubleshooting and software management, Entertainment and Data and file storage, Data and file storage and Troubleshooting and software management, and Mobile device basics and Data and file storage.

C. MDPQ-14 - A SHORT FORM OF MPDQ-28

Similar to creation of short form of the MDPQ-46, named the MDPQ-16, presented in Roque and Boot [1] where 16 items (two items per each of the eight sub-scales) were extracted from the pool of 46 original items on the basis of PCA performed separately on each sub-scale, we extracted 14 items (two items per each of the seven sub-scales) with the largest factor loadings in our MDPQ-28 CFA model to form our version of short form – MDPQ-14.

D. CRITERION VALIDITY

To assess criterion validity of the MDPQ-46, the MDPQ-28, and the MDPQ-14, the scale scores were calculated for each of the three MDPQ versions for all participants in the sample. Because discriminant validity among factors in the MDPQ-28 was not fully established and the correlations between factors were fairly high (i.e., each factor correlated

TABLE 2. Factor loadings, convergent validity and reliability of the MDPQ-28.

Construct	Item	Loading	AVE	CR	α
Mobile Device Basics	Navigate onscreen menus using the touchscreen.	.519			
	Adjust the screen brightness.	.787	.569	.791	.774
	Connect to a Wi-Fi network.	.904			
Communication	Open emails.	.963			
	Send emails.	.941			
	Store email addresses in an email address book or contact list.	.672	.751	.937	.926
	View pictures sent by email.	.951			
	Send pictures by email.	.766			
Data and File Storage	Transfer information (files such as music, pictures, documents) on my mobile device to my computer.	.634			
	Transfer information (files such as music, pictures, documents) on my computer to my mobile device.	.692	.439	.701	.696
	Store information with a service that lets me view my files from anywhere (e.g. Dropbox, Google Drive, Microsoft Onedrive).	.661			
Internet	Use search engines (e.g. Google, Bing).	.768			
	Find information about local community resources on the Internet.	.887			
	Find information about my hobbies and interests on the Internet.	.887			
	Find health information on the Internet.	.825	.576	.903	.899
	Read the news on the Internet.	.671			
	Bookmark websites to find them again later (make favorites).	.567			
	Save text and images I find on the Internet.	.645			
Calendar	Enter events and appointments into a calendar.	.870			
	Check the date and time of upcoming and prior appointments.	.813	.722	.886	.885
	Set up alerts to remind me of events and appointments.	.865			
Entertainment	Use the devices online store to find games and other forms of entertainment (e.g. using Apple App Store or Google Play Store).	.550	.458	.714	.650
	Watch movies and videos.	.723			
	Read a book.	.741			
Troubleshooting and Software Management	Update games and other applications.	.890			
	Close games and other applications.	.599	.594	.852	.846
	Delete games and other applications.	.767			
	Upgrade device software.	.798			

Note. N = 50.

TABLE 3. Discriminant validity of the subscales in the MDPQ-28.

Construct A	Construct B	Correlation	Squared Correlation	AVE A	AVE B
Communication	Internet	.721	.520	.751	.576
Communication	Calendar	.338	.114	.751	.722
Communication	Entertainment	.319	.102	.751	.458
Communication	Troubleshooting & Software Manag.	.603	.364	.751	.594
Mobile Device Basics	Communication	.544	.296	.569	.751
Communication	Data and File Storage	.544	.296	.751	.439
Internet	Calendar	.598	.358	.576	.722
Internet	Entertainment	.577	.333	.576	.458
Internet	Troubleshooting & Software Manag.	.677	.458	.576	.594
Mobile Device Basics	Internet	.736	.542	.569	.576
Data and File Storage*	Internet	.827	.684	.439	.576
Calendar	Entertainment	.550	.303	.722	.458
Calendar	Troubleshooting & Software Manag.	.724	.524	.722	.594
Mobile Device Basics	Calendar	.708	.501	.569	.722
Data and File Storage	Calendar	.524	.275	.439	.722
Entertainment*	Troubleshooting & Software Manag.	.680	.462	.458	.594
Mobile Device Basics	Entertainment	.461	.213	.569	.458
Data and File Storage*	Entertainment	.788	.621	.439	.458
Mobile Device Basics	Troubleshooting & Software Manag.	.669	.448	.569	.594
Data and File Storage*	Troubleshooting & Software Manag.	.751	.564	.439	.594
Mobile Device Basics*	Data and File Storage	.694	.482	.569	.439

Note. N = 50. *Pairs of factors with not acceptable discriminant validity.

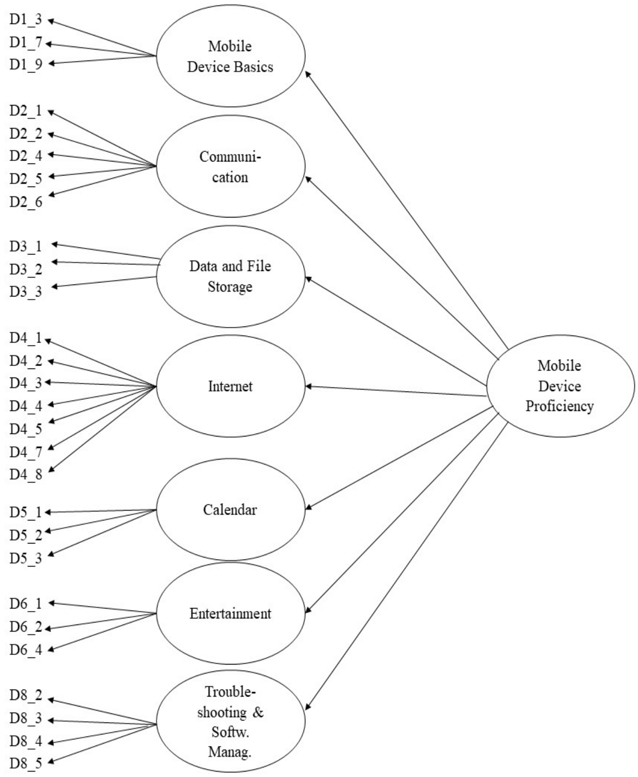

FIGURE 3. The MDPQ-28 as a second-order factor construct with seven first-order factors.

TABLE 4. Pearson's correlation coefficients between MDPQ scores and two usability metrics.

Scale[a]	TS (Android)	TS (GLP)	TE (Android)	TE (GLP)
MDPQ-46	.661	.601	.643	.421
MDPQ-28	.667	.586	.637	.405
MDPQ-14	.654	.565	.610	.379

Note. N = 50. [a] All correlations are significant at p < .05 level. TS – Task success. TE – Overall average task efficiency. GLP – GoLivePhone.

fairly high with at least one other factor), the simple summation of item scores over all items in the scale was applied to the MDPQ-28 and MDPQ-14. According to Brown [39] this is a recommended approach since our results suggested a second-order factor structure with one second-order construct and seven first-order factors (Figure 3). Conversely, to calculate the MDPQ-46 total scores we used a scoring scheme of summation of subscales' average scores as suggested by Roque and Boot [1].

The three new variables with scale scores were then correlated with two metrics measuring the objective performance of participants in usability tests on Android and GLP launcher.

Pearson's correlation coefficients are shown in Table 4. Scores for all three versions of the MDPQ were significantly positively correlated with task success and task efficiency on both launchers, with estimates spanning from .379 (correlation between MDPQ-14 scores and average task efficiency on GLP) to .667 (correlation between the MDPQ-28 scores and overall task success on Android). Since Jang *et al.* [40] suggested that criterion validity coefficients of $\geq .60$ are considered high, while those between .30 and .60 are considered moderate to good, we can conclude that our results indicate acceptable criterion validity due to small sample size and moderate to good estimates of correlation coefficients.

Moreover, correlations between the scores of all three versions of the MDPQ and average task efficiency on GLP launcher are smaller than correlations between the MDPQ scores and average efficiency on Android. Thus, we tested whether these differences were significant (i.e., a within scale comparison of correlation estimates with the two usability metrics).

The *p*-values for these t-Tests were non-significant ($p > .05$): for all three MDPQ scores there was no significant difference in the strength of correlation estimates between average task efficiency for GLP and for Android (Table 5).

TABLE 5. A within scale comparison of correlation estimates with the two usability metrics: Two-sided t-Test of the difference between two dependent correlations with one variable in common.

Metrics	Statistics	MDPQ-46	MDPQ-28	MDPQ-14
TS (Android) vs. TS (GLP)	Z-score	0.332	0.280	0.305
	p (2-tail)	0.740	0.780	0.760
TE (Android) vs. TE (GLP)	Z-score	1.021	0.880	0.842
	p (2-tail)	0.307	0.379	0.400

Note. N = 50. TS – Task success. TE – Overall average task efficiency. GLP – GoLivePhone.

A similar conclusion about the robustness of the MDPQ can be drawn with regard to task success metric.

Further, we tested whether there were significant differences between the MDPQ scales in terms of correlations with the two usability metrics (i.e., a between scale comparison of correlation estimates with the two usability metrics). For example, we tested if the correlation between the MDPQ-28 score and task success on Android (r_{28} = .667 in Table 4) was significantly different from the correlation between the MDPQ-46 with task success on Android (r_{46} = .661). The *p*-value of t-Test for this comparison was .796 (Table 6), indicating a non-significant difference. In other words, the results suggested that the MDPQ-46 and the MDPQ-28 have the same level of criterion validity when task success was used as the criterion variable. In fact, the results remain consistent when task efficiency was taken as the criterion variable as well as when the MDPQ-46 was compared to the MDPQ-14 and the MDPQ-28 to the MDPQ-14 along the two criteria.

TABLE 6. A between scale comparisons of correlation estimates with the two usability metrics: Two-sided t-Test of the difference between two dependent correlations with one variable in common.

Scales in comparison	Statistic	TS (Android)	TS (GLP)	TE (Android)	TE (GLP)
MDPQ-46 vs. MDPQ-28	Z-score	-0.258	0.675	0.251	0.635
	p (2-tail)	.796	.500	.802	.526
MDPQ-46 vs. MDPQ-14	Z-score	0.176	0.912	0.802	0.938
	p (2-tail)	.861	.362	.423	.348
MDPQ-28 vs. MDPQ-14	Z-score	0.444	0.721	0.887	0.791
	p (2-tail)	.657	.471	.375	.429

Note. N = 50. TS – Task success. TE – Overall average task efficiency. GLP – GoLivePhone.

V. DISCUSSION

The purpose of this investigation was to assess the construct and criterion validity of the MDPQ in older smartphone users. Our study is thus fully consistent with calls in the gerontechnology literature that digital skills on mobile devices, such as smartphones, tablet computers, or wearables are an important field of investigation, as there are notable advantages to mobile computing compared to desktop computing, and a lack of mobile device proficiency may discourage older adults from adopting innovative mobile health and social care services that could substantially improve their quality of life [9], [41].

In contrast with previous reports on the design and validation of the MDPQ and similar measures [1], [42]–[44], the analyses reported here are confirmatory rather than exploratory, as they are based on statistical procedures and techniques that enable a confirmatory validation of the factorial structure and predictive potential of the MDPQ. According to our findings, the validation of the MDPQ results in different outcomes in terms of convergent, discriminant and criterion validity, suggesting that choice of evaluation perspective (i.e., which type of validity is taken into account during the evaluation) can have important implications from a conceptual and a practical point of view.

On the conceptual level, the results revealed that a modified MDPQ with 28 items (i.e., the MDPQ-28) needed to be developed to account for the characteristics of older adults with prior experience with smartphones. In fact, our results unveiled that many items in the MDPQ-46 did not discriminate among older smartphone users at the desired level of attribute intensity. For example, almost all participants in the sample as smartphone users reported to know how to turn the device on and off. Since one of desirable qualities of a measurement scale is (also) variability within items [26], further work is warranted to design scale items that would be able to better discriminate differences among older smartphone users in terms of mobile devices basics; in particular, considering the rapid pace of mobile computing advances [41] which might turn today's basic skills into taken-for-granted "defaults" in the future.

Moreover, 12 indicators in the MDPQ-46 were identified that were not sufficiently correlated with the corresponding factors. Tellingly, CFA revealed very low factor weights on items such as "Send the same email to multiple people at the same time", "Make purchases on the Internet", and "Take pictures and video." In addition, with reference to construct validity the results indicated a potential issue of misspecification concerning the Privacy subscale. Notably, items in the Privacy subscale have stronger correlations with items in other subscales than with items within the Privacy subscale. For instance, the item "Erase all Internet browsing history and temporary files" was strongly related to items in Internet subscale, whereas the item "Reset the device to factory settings" was strongly related to subscale measuring Troubleshooting and software management.

When 18 items in all were dropped from the MDPQ-46 the final CFA model's fit for the MDPQ-28 was satisfactory with high internal consistency for all seven subscales. Nevertheless, the MDPQ-28 model provided relatively poor evidence of discriminant validity. In fact, for five pairs of factors we were not able to demonstrate adequate factor distinctiveness. That is, the MDPQ-28 provided valid measures of each subscale; however, some subscales overlapped substantially. This finding implies that calculating the total MDPQ score by simple summation of item scores over all scale items is very likely more appropriate than using the originally suggested scoring scheme of summation of subscales' average scores.

The second main aim of this study was to assess to what extent the self-reported survey scores of participants obtained with the MDPQ can predict the objective performance of participants in usability tests which included a set of tasks on Android and GLP smartphone launchers. Correlations were in the low to moderate range ($.379 \leq r \leq .667$) for all three versions of the MDPQ scores and metrics of task success rate on Android and GLP launcher as well as task efficiency on Android launcher, indicating that consistent association existed between the MDPQ scores and the objective performance of participants in usability testing. Even though Jang *et al.* [40] suggested that desirable values of validity coefficients (correlations) are $\geq .60$, the achieved range of correlation values ($.379 \leq r \leq .667$) in this study is in line with the acceptable norm. In addition, a reasonable degree of the MDPQ criterion validity was also supported by the fact that for all three versions of the MDPQ no significant difference in correlations between scale scores and usability metrics for both tested launchers was found.

Although the statistical tests were underpowered to detect small differences in criterion correlations (due to a small N), it is interesting to observe that the correlation between the MDPQ scores and participants' task success and efficiency on GLP launcher is somewhat smaller than the respective correlation between the MDPQ scores and the two metrics on Android launcher. We might speculate that participants who already were Android users might have better evaluated their level of smartphone-related skills based on their past experience with Android. Thus, it is reasonable to assume that the MDPQ would capture more information about individuals' mobile device proficiency with a smartphone launcher with which they have had experience. What additionally underpins this notion is that the MDPQ scores were more strongly correlated with task efficiency for GLP than with task success for GLP. This was also somewhat expected as task efficiency is a usability metric with more discrimination power in detecting the user's ability to operate an unknown system's interface [29]. Again, however, a word of caution is needed in interpreting the above correlation differences because for all three versions of the MDPQ the differences in correlation estimates between Android and GLP launchers were not significant neither for task success rate nor for task efficiency.

Moreover, the results did not show any statistically significant difference in criterion validity between the MDPQ-46 and the MDPQ-28. Relatedly, the results also showed that the short form of the modified MDPQ-28 (i.e., MDPQ-14) has the same strength of association with criterion metrics as its corresponding long version. This indicates that short scale form can capture enough information to measure mobile device proficiency accurately in the context of older smartphone users, suggesting that short scale could be more convenient to use with older adults because it has less items and can reduce the burden on older participants in a study setting [45].

The above conceptual findings might be distilled into four implications for practicing gerontechnology researchers interested in using the MDPQ. First, although several prior studies investigated the reliability and validity of the MDPQ as a measure of smartphone and tablet computer proficiency on different samples of subjects, the herein presented findings suggest that practitioners should always assess its validity before implementing it in a research setting and/or intervention program. In particular, the weight of the presented evidence favors a conservative application of the MDPQ when researchers are dealing with a specific sub-population of older adults (e.g., high-skilled smartphone users) and/or when their application of the MDPQ is aimed at a particular group of mobile computing technology (e.g., smartphone, tablet computers). Second, the MDPQ seems to be a reasonably robust measure in terms of respondent's self-assessment of their experience with a particular mobile operating system. Nevertheless, since we found some indication of differences in criterion validity between GLP and Android launchers, it would be feasible for practitioners to control for what kind of mobile operating system users had in mind when answering the scale. Third, the short MDPQ scale (i.e., MDPQ-14) has demonstrated comparable criterion validity to its respective long version (i.e., MDPQ-28). In research settings where considerable burden on participants is expected, short scales might be thus preferred over long ones. Fourth, we would suggest to practitioners, interested in using only the MDPQ subscales, to carefully evaluate the discriminant validity of subscales on their data. While our findings support the utilization of the MDPQ-28 for an evaluation of individual's overall skillfulness, they do not provide convincing evidence of its valid application on a subscale level.

Naturally, the analyses here have limitations, including the use of a small and homogenous (with respect to socio-demographic characteristics, smartphone experience) non-probability sample of older adults which reduces the generalizability of the herein presented results. A replication study on larger and more heterogeneous sample of older smartphone users might be worth considering to increase statistical power and assess the measurement invariance [38] of the MDPQ across different sub-populations of older adults. Relatedly, administrating the instrument in the context of an experiment with smartphone launchers could have also indirectly influenced the participants' understanding of scale items. Since the existing literature has suggested that older adults can respond differently to usability testing situations [30], questions remain about what might happen in more naturalistic settings or field studies. Of course, it is also possible that the reasons for empirical disconfirmation of the MDPQ-46 are incorrect instrument administration by researchers and/or mistaken responses by the participants in the experiment. In contrast with all prior work on the MDPQ that was based on self-administered surveys, in this study

TABLE 7. List of items included in the four versions of the MDPQ.

Id	MDPQ-46	MDPQ-28	MDPQ-14	MDPQ-16	M	ME	SD
Mobile Device Basics							
D1_1	Turn the device on and off.[a]				5.0	5.0	0.1
D1_2	Charge the device when the battery is low.[a]				4.9	5.0	0.2
D1_3	Navigate onscreen menus using the touchscreen.	X		X	4.6	5.0	0.9
D1_4	Use the onscreen keyboard to type.[b]			X	4.7	5.0	0.8
D1_5	Copy and paste text using the touchscreen.[b]				2.3	1.5	1.5
D1_6	Adjust the volume of the device.[b]				4.8	5.0	0.6
D1_7	Adjust the screen brightness.	X	X		3.9	5.0	1.6
D1_8	Adjust the text size.[b]				3.3	4.0	1.8
D1_9	Connect to a Wi-Fi network.	X	X		3.9	5.0	1.6
Communication							
D2_1	Open emails.	X	X		4.1	5.0	1.5
D2_2	Send emails.	X		X	3.9	5.0	1.6
D2_3	Send the same email to multiple people at the same time.[b]				3.0	3.0	1.8
D2_4	Store email addresses in an email address book or contact list.	X			3.3	4.0	1.8
D2_5	View pictures sent by email.	X	X		3.9	5.0	1.6
D2_6	Send pictures by email.	X		X	3.7	4.0	1.6
D2_7	Post messages to Social Media Networks (e.g. Facebook, Twitter, Instagram, Google Plus). [b]				2.0	1.0	1.6
D2_8	Use instant-messaging (e.g. AIM, Yahoo Messenger, MSN Messenger).[b]				1.6	1.0	1.4
D2_9	Use video-messaging (e.g. Skype, Google, Hangout, Facetime).[b]				2.3	1.0	1.8
Data and File Storage							
D3_1	Transfer information (files such as music, pictures, documents) on my mobile device to my computer.	X		X	3.0	3.5	1.8
D3_2	Transfer information (files such as music, pictures, documents) on my computer to my mobile device.	X	X	X	2.2	1.0	1.6
D3_3	Store information with a service that lets me view my files from anywhere (e.g. Dropbox, Google Drive, Microsoft Onedrive).	X	X		2.0	1.0	1.6
Internet							
D4_1	Use search engines (e.g. Google, Bing).	X			3.8	5.0	1.6
D4_2	Find information about local community resources on the Internet.	X	X		3.2	4.0	1.8
D4_3	Find information about my hobbies and interests on the Internet.	X	X	X	3.1	3.5	1.9
D4_4	Find health information on the Internet.	X		X	3.2	4.0	1.9
D4_5	Read the news on the Internet.	X			3.4	4.0	1.8
D4_6	Make purchases on the Internet.[b]				1.6	1.0	1.4
D4_7	Bookmark websites to find them again later (make favorites.)	X			2.1	1.0	1.7
D4_8	Save text and images I find on the Internet.	X			2.4	1.0	1.7
Calendar							
D5_1	Enter events and appointments into a calendar.	X	X	X	3.2	4.0	1.9
D5_2	Check the date and time of upcoming and prior appointments.	X		X	2.9	3.0	1.9
D5_3	Set up alerts to remind me of events and appointments.	X	X		3.1	4.0	1.9
Entertainment							
D6_1	Use the devices online store to find games and other forms of entertainment (e.g. using Apple App Store or Google Play Store).	X		X	2.3	1.0	1.8
D6_2	Watch movies and videos.	X	X		1.7	1.0	1.5
D6_3	Listen to music.[b]			X	2.8	2.5	1.9
D6_4	Read a book.	X	X		1.4	1.0	1.2
D6_5	Take pictures and video.[b]				4.8	5.0	0.5
Privacy							
D7_1	Setup a password to lock/unlock the device.[c]			X	2.7	2.0	1.8
D7_2	Erase pictures and videos stored on the device. [c]				4.5	5.0	1.0
D7_3	Erase all Internet browsing history and temporary files.[c]			X	2.4	1.0	1.8
D7_4	Reset the device to factory settings, erasing all account information.[c]				1.6	1.0	1.4
Troubleshooting and Software Management							
D8_1	Restart the device when it is frozen or not working right.[b]				4.7	5.0	0.8
D8_2	Update games and other applications.	X	X	X	2.9	1.0	2.0
D8_3	Close games and other applications.	X			3.8	5.0	1.8
D8_4	Delete games and other applications.	X		X	3.0	3.5	1.9
D8_5	Upgrade device software.	X	X		2.7	1.0	2.0

Notes. N = 50. All scale items are measured on a five-point scale: "1 = never tried", "2 = not at all", "3 = not very easily", "4 = somewhat easily", and "5 = very easily". "*X*" indicates inclusion of a scale item, empty cell indicates omission of an item from the list. [a] Item omitted from the MDPQ-46 scale due to lack of variability. [b] Item omitted from the MDPQ-46 scale due to low factor loading. [c] Item omitted from the MDPQ-46 scale due to factor misspecification.

personal interviewing was used which might lead to potential measurement errors associated with ''survey mode effects'' such as social desirability or interviewer effect [46]. Since the impact of differential administration mode on the MPDQ is not yet clear, future research might also assess its sensitivity to different survey modes in naturalistic and lab settings. Next, due to the confirmatory scope of this study and its small sample size, we fully respected the originally proposed MDPQ factor structure throughout the MDPQ refinement process. However, given the low internal consistency of one of the MDPQ-46 subscales and, in particular, a non-identifiable measurement model solution, one necessary area for further research could be the design of refined indicators and the verification of their appropriateness with exploratory factor analysis on a larger sample of subjects (see also [26]). Using a two-stage exploratory approach developed by Gerbing and Hamilton [47] to investigate the dimensionality of scale items might offer an alternative lens for conceptualizing and measuring subscales that were shown to have unacceptable discriminant validity.

VI. CONCLUSION

The main contribution of this paper is to further refine assessment tools aimed at understanding older adults' mobile device proficiency. More refined tools can facilitate gerontechnology research and the ability to efficiently improve the technology proficiency of less proficient older adults. MDPQ validation previously involved assessing the skills of older adult samples with a wide range of proficiency. However, the changes suggested here are necessary to differentiate proficiency among samples of older adult smartphone users. Better and more nuanced measures have the potential to further promote the goals of ensuring that individuals of all ages can benefit from new technologies.

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APPENDIX

See Table 7.

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