Cognitive Variability Factors and Passphrase Selection

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Abstract. Security policies require a secret code to access electronic information. Challenges exist between the usability and memorability of passwords. This study spotlights individualistic behavioral assimilation of passphrase styles for design insight and recall abilities. Data captured categorical authentication behavior toward enhanced usability outcomes. Validated locus of control personality and memory associative instruments demonstrated the internal and external personality types and cognitive response types that contribute to the systematic quest toward a more memorable passphrase scheme. Personalized criteria contributed to practical evaluation employing a repeated measures structure. This study tested 58 participants who successfully completed a passphrase survey consisting of four rulesets applied to imposed and user created passphrases designed for repeated measures. Although electrophysiological data was collected, it was not analyzed in time for this publication. Results indicate that memory associative factors of cognition represent a significant factor in the recall of 75 percent of imposed passphrase category types. The locus of control and memory associative variables are significant at the .05 level. Internally controlled participants preferred the created room objects and created no vowel passphrases. Additionally, the created room objects and animal association passphrases ranked the highest among the externally controlled subjects. The imposed passphrases constructed without vowels and associated with animals received the least recall. This descriptive study informs passphrase usability identifying cognitive demands that impact memory.

Keywords: Passphrase Authentication, Locus of Control Personality, Cognition, Memorability

1 Introduction

Password objectives spanning more than 40 years have positioned the importance of security and convenience in human computer interaction. Password security continues to dominate computer authentication in a non-standard system [20]. Although, Herley, Van Oorschot, and Patrick (2009) question if passwords will be universally used by the year 2019, the secret keyword remains ubiquitous. Varying password selection criteria persists with inconsistent conditions among websites [6] and usability problems continue to exist with passwords [22].

Bonneau, Herley, Van Oorschot, and Stajano (2012) report the difficulty to replace passwords given security and human interaction weaknesses. Usability, deployability, and security advantages framed their focus on evaluation principles. Results from their study suggest passwords are not expected to be a displaced authentication technology. Therefore, the application of a criteria based methodology furthered their discussion on computer authentication.

Establishing a memorable password is expected to lessen the burden of password creation and recollection. Addas, Thorpe, and Salehi-Abari (2019) suggest the use of a geographic cue to assist user memory during passphrase recall. However, recollection data indicated that while users were not constrained to a passphrase format, allowing a free form passphrase suggests to impede the memory advantage of utilizing the GeoHint authentication system. Another study conducted by Yıldırım and Mackie (2019) supports memorability proposed password composition guidelines that suggest to augment memorability and alleviate the difficulty of managing multiple accounts with unique requirements.

Grassi, Garcia, and Fenton (2017) define successful digital authentication of a memorized secret to a system when a subscriber provides secret information for that identity. Unlike symmetric keys that are controlled by the verifier, memorized passwords are constructed by the user and are expected to be successfully recalled. Therefore, similar passwords may be composed and used in other logins. The reuse of password credentials support memorability by lessening the burden of recall errors. Herley, Van Oorschot, and Patrick (2009) offer insight beyond passwords. The current memorability challenge is offset by password resets. However, security implications and user management of numerous passwords are concerns that impact the progress of enhanced user authentication that addresses security and usability.

Passphrase structures simulate natural language and therefore suggest to increase usability [22]. A password memory study devised a way for users to create memorable passphrase consisting of four words. Jeong, Vallat, Csikszentmihalyi, Park, and Pacheco (2019) propose that electing four random words is more secure than a standard password consisting of a combination of characters and numbers. Besides collecting passwords for security reasons, Bonneau and Preibusch's (2010) study indicate that not all websites necessitate security passwords. In fact, passwords are collected by websites to establish a database of user information targeted for other reasons such as marketing purposes that add weight to usability efforts. Mitigating password enrollment, resets, sharing, and reuse are motives that contribute to this passphrase study. The research examines memorable communication between the user and computer with emphasis on individual selection and recollection of various passphrase types for discrete locus of control personalities and behavioral preferences.

2 Research Design

The passphrase study is designed to expose all university respondents, N=58, to all levels of the independent variable predictors that result in regulating variance and alleviating the random assignment of the sample [23]. Repeated measures identify within subject differences in passphrase selection and memorability and it is expected to result in participant similarities that differ among others [8]. Subjects were scheduled for 90 minute appointments at the University of Hawai'i at Mānoa's Hawaii Interdisciplinary Neuroscience Technology Laboratory (HINT) lab. The survey was administered using an anonymized Qualtrics platform licensed by the University of Hawai'i at Mānoa. Physiological data was collected measuring heart rate, skin conductance, and facial corrugator muscle using the BIOPAC Systems, Inc. equipment. Electronic sensors, amplifiers, and transducers complied with the criteria of the International Organization for Standardization that detail laboratory methods for quality management principles [21]. The results from the electrophysical data collection will be reported in the future.

This study intends to predict associations based on theory, clearly defined research questions, hypotheses testing and regression analysis. The survey was processed through a systematic progression of pretesting design principles. Three pilot studies were conducted to arrive at the final survey. The completed design is governed by four rule sets for each imposed and user constructed category that are defined by four words containing five characters.

The survey data collected was password secured and manually scored by the researcher. Data was cleaned by comparing the responses to the passphrase requirements and categorizing individual records for the associated variable scores. All conditions will be tested using IBM's statistical package for the social sciences (SPSS) that assess the significance and effects of interactions [10]. Data analysis is expected to reveal relationships and patterns to predict the effects of cognition and locus of control personality on passphrase construction and memorability behavior.

3 Passphrase Instruments

Fifty-eight participants were presented with a survey consisting of imposed and user constructed passphrase recall based on four rulesets. Data was collected using existing validated instruments as well as a passphrase survey that was tested using three pilot studies. In addition to the various passphrase memory types, the survey contained Rotter's (1966) locus of control (LOC) personality test and Ekstrom, Dermen, and Harman's (1976) memory associative factor cognitive test. During passphrase recall, the Stroop (1935) word and color test was randomly distributed throughout the survey to interrupt immediate retrieval from working memory. Table 1 illustrates the characteristics of the survey questions.

Table 1. Passphrase Survey Composition

Question Type	Characteristics	Instrument	Usefulness
Self-report	Expression of attitude, belief, feeling	LOC Internal External Test	Indicative of self-knowledge
	Identity	Demographics	Indicative of self-knowledge
Closed ended	Multiple choice format	LOC Internal External Test	Indicative of self-knowledge
	Memory recall of numbers and names	Memory Associative Tests	Indicative of working memory processing
	Physiological responses	EDA, EKG, fEMG	Psychophysiological inferences of emotion
Open ended	Memory recall of passphrases	Passphrase Recall Tests	Indicative of working memory processing
	Passphrase Construction	Passphrase Construction Rule Sets	Indicative of cognitive processing

Source: Adapted from Spector (2004, p. 253)

3.1 Locus of Control Personality

The passphrase survey was designed using self-reports of the locus control personality test. Locus of control deciphers a situation to inform individual approaches to one's surroundings [16]. Locus of control is interpreted as internal or external personality. Responses are construed to attribute behavior based on self-perception that are internally determined. Situations contingent on the external or to be controlled by destiny are revealed in the validated generalized reinforcement questions rooted in social, academic, and attitudes of living [24].

The locus of control personality scale is indicative of internal traits that have a positive response to perceived regulation of behavior expectancies that have been modified and applied to predict latent behavior [15]. Factors representing internally controlled personalities are reliant on personal unique characteristics. Externally controlled individuals distinguish events with unpredictability allowing environmental factors to add complexity to distinctive contexts [24].

Results of the measurements surrounding decision making are implied to indicate personal assessments of the presented stimuli. Responses are expected to amplify behavioral responses to cognitive stressors that impact this design studying execution during passphrase construction and recall.

3.2 The Stroop Effect on Cognitive Load

Passphrase decisions were captured during cognitive load. A rise in passwords coupled with varying usage and non-standard requirements produce usability difficulties [1]. To interfere with cognitive load, the Stroop test randomly appeared throughout the survey as a distractor mechanism. It prompted the participant to distinguish the word from the ink color. Therefore, if the word BLUE is displayed in yellow ink, the correct answer is blue. The obstruction interrupts processes allocated to attention and is most effective when cognitive load is high [17].

3.3 Memory Associated Factor-Referenced Cognitive Tests

To assess working memory retrieval, this study employed two memory associative factor tests. The assessment of immediate recovery was supported by three pilot tests. Results are expected to lighten the burden of memorability and authentication by examining cognitive load and informing research on passphrases targeted to support recollection. Respondents were timed to memorize, recall, and match 15 numbers with objects and 15 first names to last names [9]. Results are expected to provide perception to immediate recall abilities. Cognitive processing that effectively organizes associations to arrive at a meaningful command of grouping words advances the ability to manage elements of mental effort attributed to load. Therefore, this study approaches the ability of working memory to advert the diminishing effects over time.

3.4 Passphrase Rulesets

The passphrase survey was designed with four rulesets that required 16 repeated recalls for each category. The imposed passphrase and participant created passphrases were used to classify individual responses to these classifications. Each passphrase consisted of four words requiring five characters per word. Clear instructions for each question supported cognitive load. To create a passphrase, descriptions for each ruleset were defined by the following: (a) vowels removed from all words; (b) select a word for each category of food, nature, sports, and transportation; (c) select visual objects located in the test room; (d) select words associated with an animal. The same rulesets applied to passphrases that were imposed on the participants.

3.5 Psychophysiological Inferences of Emotion

Each participant was measured for psychophysiological factors including heart rate, skin conductance, and facial electromyography. Electronic sensors captured signals from the electrocardiogram (EKG), electrodermal activity (EDA), and facial electromyography (fEMG). Visible occurrences in these physiological states are expected to generate quantifiable dimensions of emotion to passphrase events [7].

Physiological responses demonstrated by reactions to cognitive processing are targeted on behaviors from the autonomic nervous system that traverse to the sympathetic

nervous (SNS) and parasympathetic nervous (PNS) systems. Therefore, arousal in electrical signals were captured by the heart rate and skin conductance to indicate homeodynamic effects regulated by the demand of cognitive stimuli [3]. Whereas the corrugator muscle exhibits a non-reflective affect of emotion [25], such activity will be differentiated through activation measurements.

Variability in physiological responses are anticipated to reveal participant experiences during the processing of passphrase selection and recall. Reactions from the passphrase survey stimuli were designed to provide physiological understanding of working memory processing during the encoding and decoding of passphrases. As of this writing, measurements collected were not analyzed for heart rate pulses, facial electromyography muscle activation, and skin conductance arousal significances.

3.6 Passphrase Survey

The passphrase survey consisted of 12 variables measuring 187 items including locus of control, memory associations, and passphrase recall for imposed and created passphrases based on four rulesets shown in Table 2.

Table 2. Passphrase Survey Items

Locus of Control Personality	
Internal Locus of Control	29 items
External Locus of Control	29 items
Memory Associative Factors	
Object Number Associations	15 items
First Name Last Name Associations	15 items
Imposed and User Created Passphrase Rulesets	
Four Words, 5 Characters per Word	
16 Recalls per Category	
No Vowels	32 items
Four Categories: Food, Nature, Sports, Transportation	32 items
Room Objects	32 items
Animal Associations	32 items
Stroop Word and Color Test	
Randomized distractor used during passphrase recall	98 items
Demographics	
Number of Logins, Age, Gender, Study Focus/Major, Employment Status	5 items

4 Passphrase Survey Descriptive Results

This study consisted of 58 university participants who were exposed to all levels of the independent variables alleviating the essential random designation of subjects [23]. The repeated measures design categorizes discrete differences in passphrase recall and selection among the sample [8]. An anonymized Qualtrics survey was used to present the questionnaire that was accompanied by instructions and examples to facilitate working memory [19].

4.1 Demographics

Figure 1 displays the sample, (N=58), comprised of subjects who manage an average of 14 active online accounts. Fifty-nine percent are currently employed. The average age is 21 years old.

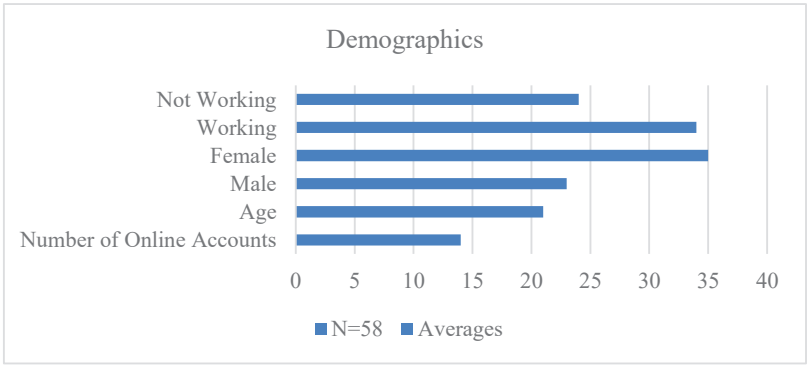

Fig. 1. Demographics

4.2 Locus of Control and Memory Associative Measures

The repeated measures within subjects effects between the memory associative and locus of control variables resulted in the significance of (p=0) and the rejection of the null hypotheses, which is below the level of ($p \leq .05$). The partial Eta Squared reported that 51.5 percent of the sample is attributed to variability. Tukey's test resulted in the significance (p=0) in a pairwise comparison. Therefore, the mean difference is significant at the .05 level.

4.3 Locus of Control and Memory Associative Factors on Passphrase Types

The sample results indicated that 53 percent of participants were internally controlled while 62 percent scored below the mean for working memory recall of numbers to objects and first names to last names cognitive factor analysis.

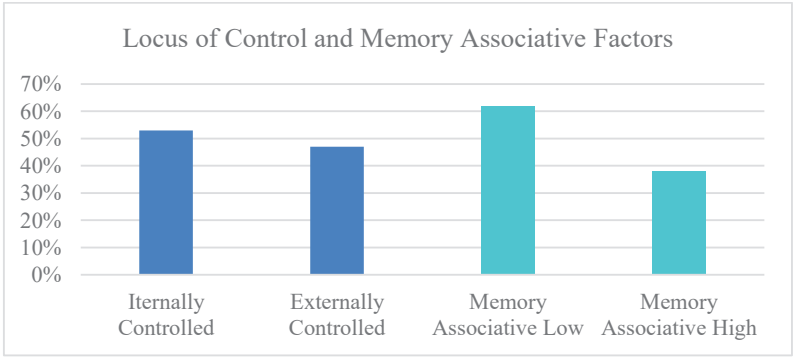

Fig. 2. Locus of Control and Memory Associative Factors Sample

Specifically, the distribution for internal locus of control resulted in 33 percent who scored below the mean for cognitive processing compared with 21 percent who achieved scores indicative of high memory association ability. The majority of external controlled participants scored low on the factor analysis instrument. The outcomes are shown below in the Figure 3.

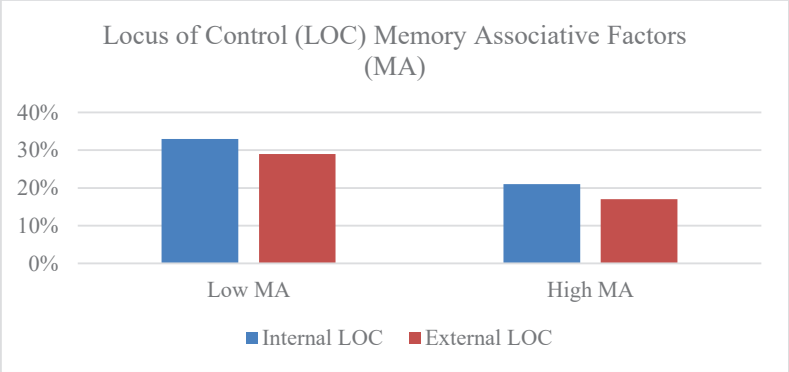

Fig. 3. Locus of Control and Memory Associative Factors Descriptives

4.4 Locus of Control and Passphrase Types

The repeated measures within subjects effects between the locus of control variable and imposed passphrases resulted in the significance of (p=0) and the rejection of the null hypotheses, which is below the level of (p≤.05). The partial Eta Squared reported that 38.6 percent of the sample is attributed to variability. In comparison, the locus of control variable and the created passphrases resulted in the significance of (p=.036) and the rejection of the null hypotheses, which is below the level of (p≤.05). The partial Eta Squared reported that 4.40 percent of the sample is attributed to variability.

4.5 Memory Associative Correlation and Passphrase Types

Results displayed in Table 3 depict the memory associative variable was significant with the recall of three forms of imposed passphrases: (a) four categories (p=.023), (b) room objects (p= .006), and (c) animal associations (p=.001). Therefore, the memory associative test was significant at the (p≤.01) level for correlation with the imposed room objects and animal association passphrases as well as the created four categories passphrase rule (p=.003). The Wilks' Lambda (p=.05) statistic identified differences between the means of the memory associative effect on the imposed passphrase sets. Furthermore, unlike the memory associative effect on the created passphrase rule sets, the imposed passphrase rule sets reported a significance of (p=.002) with a Partial Eta ratio of variance that suggested 41.73 percent of variance can be explained by the memory associative variable. Regarding the effect of memory associations and the created passphrase rule sets, Roy's Largest Root multivariate hypotheses reported significance at (p=.002). A complete list of positive correlations among passphrase variables relating to the cognitive test for immediate retrieval is presented below.

Table 3. Correlations for Memory Associative and Passphrase Types (N=58)

	I4C	IRO	IAA	C4C	CRO
Memory Associative (MA)	.023*	.006**	.001**	.003**	
Imposed Four Categories (I4C)					
Imposed Room Objects (IRO)	.033*				
Imposed Animal Associations (IAA)	.046*	.000**		.022*	
Created Four Categories (C4C)					
Created Animal Associations (CAA)				.022*	.003**
Created Room Objects (CRO)					

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

The majority of respondents were internally controlled. These subjects scored highest in all eight passphrase types. The imposed passphrase types are: no vowels (INV), four categories (I4C), room objects (IRO), and animal associations (IAA). The created passphrase types are: no vowels (CNV), four categories (C4C), room objects (CRO), and animal associations (CAA). As shown in Figure 4, internal control subjects scored the highest recalling the created room objects passphrase.

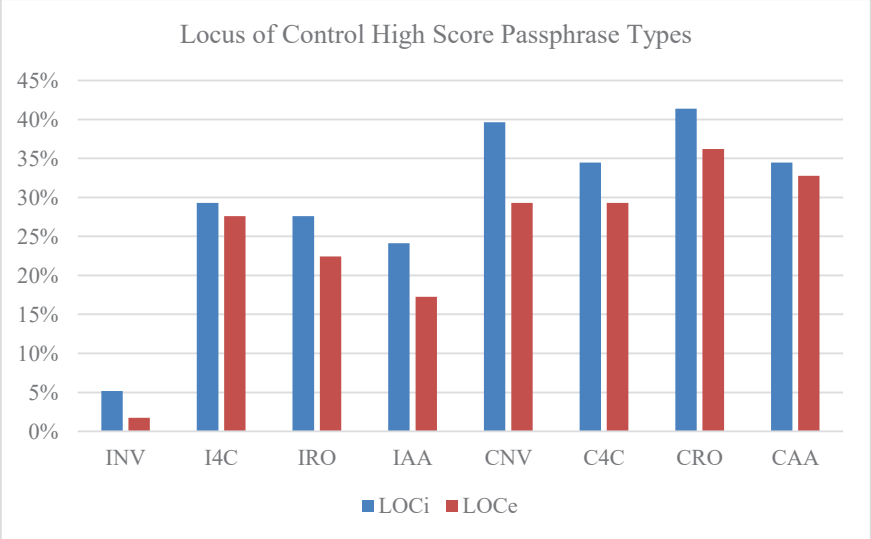

Fig. 4. Locus of Control High Score Passphrase Types

The created no vowels passphrase and created room objects were ranked among the highest recall categories by the internally controlled. Additionally, 69 percent of the sample were effective in creating and recalling a passphrase without vowels. External controlled subjects favored to create passphrases based on room objects and animal associations. Respectively, these subjects accounted for 36 percent of the total 78 percent and 33 percent of the total 67 percent.

The imposed four category passphrases followed by imposed room objects received the highest scores for both internal and external controlled subjects. Internals preferred the room objects while externals were inclined to the four categories which accounted for a 28 percent success rate by each group.

In contrast to the favored created no vowels passphrase, the imposed no vowel version received the lowest success for both internal and external locus of control respondents. Subsequently, five percent of the internal controlled and two percent of the external controlled sample recalled this passphrase type. The overall approach to recalling a complex passphrase resulted in partial success of the four word passphrase. Individual encoding data will be analyzed in the future.

4 Concluding Remarks

Responses to passphrase recall measured short term memory using associative factors. The locus of control personality test reflected dichotomous answers that represent the underlying performance of internal and external traits. This study was designed to predict relationships in non-experimental research that utilize causal inference based on statistical results of hypotheses testing of the research questions. The predictive qualities of cognition were measured for processing of passphrase types that were presented to the subjects for recall. Presenting passphrases that were constructed of categories, room objects, and animal associatives resulted in a significant relationship between memorability factors of the passphrase structures. This finding is indicative of a systematic process to aid cognitive recall and avert its decrease over time.

The locus of control antecedent trait is perceived to influence decision making during passphrase selection and recall. Behavior moderated by the environment or external forces are predicted to reject unique conditions that are expected to be innate to those encompassing situational command [16]. Consequently, controlled individuals are perceived to embrace predictable abilities compared with peripheral based contingencies [18].

The created passphrase room objects received the highest recall ability from internally and externally controlled subjects. It can be inferred that visual objects assist in recalling passphrases. Subsequently, internals selected the created no vowels category whereas externals preferred the created animal associations.

Unlike the successes from the created rulesets, the imposed no vowel passphrase received the lowest recall from both locus of control personalities. This may be attributed to the difficulty with the four words that require a method for positive encoding. The imposed animal associations followed as the ruleset that was also problematic for memorability.

5 Future

The physiological data collected will be processed using BIOPAC's AcqKnowledge system software for electrodermal arousal patterns, heart rate frequency patterns, and activation of the facial corrugator muscle. These psychophysiological inferences are expected to reveal physical responses to the eight passphrase rulesets. Individual physiological predictors will be analyzed for correlation to cognitive processing to reflect the decision making process of constructing and selecting computer passphrases. The locus of control personality antecedent suggests to stimulate neural motion as behaviors governed by the control features are evident by pulse patterns during cognitive though processing [13]. Physiology and cognition are anticipated to establish perceptive processing to inform memorable computer authentication.

The combination of cognitive processing, locus of control personality, and psychophysiological factor outcomes are expected to provide performance insight during the processing of working memory recollection of computer passphrases. The amalgamation of diverse factors will copiously characterize individual perceptions and behavior of passphrase types that strengthen the support of cognitive retrieval.

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