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Comment rendre les sites bancaires plus accessibles aux analphabètes fonctionnels?

par

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Résumé

On retrouve dans les pays développés une population importante d'analphabètes fonctionnels. Ce groupe rencontre des difficultés en lecture et en écriture, mais aussi dans plusieurs habiletés nécessaires pour bien fonctionner en société comme les habiletés mathématiques et la littératie numérique. L'utilisation d'outils numériques peut donc être compliquée, ce qui est problématique dans une société dont plusieurs services essentiels, comme les services bancaires, se font numériser. Afin de favoriser l'inclusion sociale et réduire le fossé numérique, il devient important de s'assurer que les interfaces bancaires numériques soient accessibles à cette population. L'objectif de ce mémoire est donc d'améliorer l'accessibilité des interfaces bancaires numériques pour les analphabètes fonctionnels sans nuire à l'expérience des autres utilisateurs. Dans une première étude expérimentale, le traitement neurophysiologique des mots et des icônes chez les analphabètes fonctionnels ainsi que d'un groupe contrôle est comparé à l'aide d'une tâche de recherche visuelle et l'électroencéphalographie (EEG). Les mesures suivantes ont été collectées : le temps de réponse, l'exactitude de la réponse et l'activité corticale (EEG). Le but de cette étude est d'évaluer l'efficacité des icônes comparé aux mots pour améliorer l'expérience des utilisateurs analphabètes fonctionnels et ceux avec un niveau de littératie normal. Dans une deuxième étude expérimentale, une interface bancaire numérique a été simplifiée en diminuant le nombre d'affordances offertes (le nombre de boutons) sur la page afin de réduire la densité de choix. L'expérience utilisateur entre la version actuelle du site bancaire et sa version simplifiée est alors comparée pour un groupe d'analphabètes fonctionnels et un groupe contrôle. Les participants devaient effectuer diverses réelles tâches bancaires sur les deux versions de l'interface. Les mesures suivantes ont été collectées : le temps de réalisation, le taux de succès, l'effort perçu durant les tâches et l'activité corticale (EEG). Le but de cette étude est de déterminer dans quelle mesure une réduction du nombre de boutons (la densité de choix) sur une interface bancaire numérique affecte l'expérience utilisateur des analphabètes fonctionnels par rapport au reste de la clientèle. Les résultats suggèrent que les icônes ne sont pas suffisantes par elles-mêmes pour simplifier efficacement une interface et il en est de même pour la réduction de la densité de choix. Ils suggèrent aussi que la familiarité avec l'information visuelle impacterait de façon plus importante l'expérience utilisateur des analphabètes fonctionnels. Nous concluons alors que pour améliorer l'accessibilité, plutôt que de changer le design visuel des sites bancaires, les organisations devraient s'assurer que les utilisateurs soient familiers avec l'information importante de l'interface numérique ainsi qu'avec les étapes pour accomplir les tâches essentielles.

Mots clés : accessibilité, analphabètes fonctionnels, expérience utilisateur, recherche visuelle, icônes, densité de choix, EEG

Abstract

In developed countries, there is a large population of functional illiterates. This group faces difficulties in reading and writing, but also in several skills necessary to function well in society, such as mathematical abilities and digital literacy. The use of digital tools can therefore be complicated, which is problematic in a society where many essential services, such as banking, are becoming digitized. To promote social inclusion and reduce the digital divide, it is important to ensure that digital banking interfaces are accessible to this population. The objective of this thesis is therefore to improve the accessibility of digital banking interfaces for functional illiterates without compromising the experience of other users. In the first experimental study, the neurophysiological processing of words and icons among functional illiterates and a control group is compared using a visual search task and electroencephalography (EEG). The following measures were collected: response time, response accuracy, and cortical activity (EEG). The aim of this study is to assess the effectiveness of icons compared to words in improving the experience of functional illiterate users and those with a normal level of literacy. In a second experimental study, a digital banking interface was simplified by reducing the number of affordances (the number of buttons) on the page to reduce choice density. The user experience between the current version of the banking site and its simplified version is then compared for a functional illiterate group and a control group. Participants had to perform various real banking tasks on both versions of the interface. The following measures were collected: completion time, success rate, self-perceived effort during tasks, and cortical activity (EEG). The aim of this study is to determine to what extent reducing the number of buttons (choice density) on a digital banking interface affects the user experience of functional illiterates compared to the rest of the clientele. The results suggest that icons alone are not enough to effectively simplify an interface, nor is the reduction of choice density. They also suggest that familiarity with visual information would have a more significant impact on the user experience of functional illiterates. We, therefore, conclude that to improve accessibility, rather than changing the visual design of banking sites, organizations should ensure that users are familiar with the important information on the digital interface as well as the steps to complete essential tasks.

Keywords: accessibility, functional illiterates, user experience, visual search, icons, choice density, EEG

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Liste des abréviations

Call-to-action : CTA

Électroencéphalographie : EEG

Expérience utilisateur : UX

Avant-propos

Ce mémoire fait partie de la maîtrise en gestion en expérience utilisateur de l'étudiant aux HEC Montréal et a été approuvé par l'administration du programme. Aussi, les directeurs de recherche ont approuvé l'écriture du mémoire par articles et tous les coauteurs ont approuvé leur inclusion dans ce travail. Le premier article (chapitre 2) se nomme « Comparing the Visual Processing of Words and Icons for Functional Illiterates in an Online Banking Context » et il a été accepté à la conférence « 2024 NeuroIS retreat ». Le deuxième article (chapitre 3) se nomme « Can Reducing Choice Density Improve the Accessibility of Digital Banking Interfaces for Functional Illiterates? » et il en préparation d'être soumis au « International Journal of Human-Computer Interaction ». Les projets de recherche ont été approuvés en juin 2023 par le bureau du Comité d'éthique de la recherche de HEC Montréal (2023-5388) et ont été conduits de façon éthique.

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Chapitre 1 : Introduction

Dans le monde, il y a environ 763 millions de personnes qui ne savent ni lire ni écrire (UNESCO, 2024). Cependant, dans les pays développés, on retrouve plutôt une grande population d'analphabètes fonctionnels (Vágvölgyi et al., 2016). Par exemple, au Québec, une statistique suggère qu'environ 53% de la population entre 16 et 65 ans serait considéré comme analphabètes fonctionnels (Fondation pour l'alphabétisation, 2021) et des chiffres similaires ont été retrouvé aux États-Unis (Mamedova et Palowski, 2019) ainsi que dans d'autres pays similaires (OECD, 2016). Quoique ces statistiques peuvent être exagérées dû à la complexité de l'évaluation de la littératie et de ces nombreux aspects (Roser et Ortiz-Ospina, 2024). Il reste qu'il y a un nombre substantiel d'individus avec un bas niveau de littératie qui réussissent tout de même à vivre en société.

L'analphabétisme fonctionnel implique non seulement une déficience dans les compétences en lecture et en écriture, mais aussi toute autre habileté nécessaire pour bien fonctionner en société comme les habilités numériques et la littératie numérique (Lo Prete, 2022). Il peut donc être difficile d'accomplir des tâches essentielles (appliquer pour un emploi et utiliser un site bancaire en ligne) (Cree et al., 2012; Mohammed et al., 2023a; Vágvölgyi et al., 2016) nuisant ainsi à l'intégration en société et augmentant le fossé numérique (Ahmed et al., 2019). En effet, plusieurs milieux, comme le domaine bancaire, vont favoriser la numérisation de leurs services (Chuard, 2021; Valenti et Alderman, 2021) et il devient donc important d'assurer l'accessibilité des interfaces numériques pour les analphabètes fonctionnels.

Le développement d'une interface bancaire numérique accessible pour les analphabètes fonctionnels peut s'avérer être un défi puisqu'il existe plusieurs facteurs comportementaux et neurophysiologiques de cette population à considérer. D'une part, les analphabètes fonctionnels ont leurs propres stratégies pour naviguer des environnements réels et numériques. Ces individus ont tendance à apprendre des suites d'action pour accomplir des tâches (par exemple, défiler une fois vers le haut et sélectionner le deuxième contact pour appeler son ami) enlevant ainsi le besoin de lire le texte (Knoche et Huang, 2012). Afin de réduire le stress, ils vont aussi avoir tendance à éviter des environnements non familiers et baser leur décision sur des éléments spécifiques (par exemple, le prix ou une image) (Viswanathan et al., 2005). D'autre part, n'ayant pas appris à lire à un jeune âge, les analphabètes fonctionnels ont plusieurs différences structurelles au niveau du cerveau ainsi que des déficiences cognitives (Vágvölgyi et al., 2016). En effet, plusieurs études ont trouvé une connectivité réduite entre les régions du cerveau lié au langage incluant entre les régions liées au traitement visuel précoce ainsi que celles liées au traitement linguistique de hauts niveaux (Ardila et al., 2010). Les études ont aussi trouvé, comparé à des personnes alphabétisées, une activité réduite dans ces régions lors du traitement d'informations visuelles (Dehaene et al., 2015). Cognitivement, les analphabètes fonctionnels ont des déficiences dans divers processus : la mémoire de travail, la perception, l'attention et plusieurs autres (Vágvölgyi et al., 2016 ; van Linden et Cremers, 2008). Il est donc possible d'observer que leurs façons d'interagir avec le monde et de traiter l'information soit donc bien uniques et doivent être prises en compte lors du développement d'interface accessible.

Plusieurs méthodes ont été développées et évaluées afin d'améliorer l'accessibilité des interfaces non seulement pour les analphabètes fonctionnels, mais aussi pour l'ensemble des utilisateurs. Les icônes ont particulièrement été utilisées dans plusieurs domaines dus à leur capacité d'améliorer l'affordance visuelle en permettant une compréhension rapide des éléments d'une interface (Engelbart et English, 1968; Hartson, 2003; Islam et al., 2020). Par exemple, une icône de panier d'achats indique rapidement à l'utilisateur où se trouvent les produits qu'il a sélectionnés pour l'achat. Cependant, des études dans le domaine bancaire incluant des participants analphabètes fonctionnels ont trouvé que l'efficacité des icônes pouvait dépendre du degré de familiarité d'un individu avec celles-ci (Matthews, 2019; Thatcher et al., 2006; Wiedenbeck et al., 1999). Pour des utilisateurs avec une basse littératie numérique, comme avec les analphabètes fonctionnels, les icônes peuvent alors potentiellement avoir un impact limité. Bien sûr, plusieurs autres types d'interfaces ont été testés avec des utilisateurs analphabètes ainsi que semi-analphabètes et se sont révélés bénéfiques (Islam et al., 2023; Medhi et al., 2006). Toutefois, une interface spécifiquement développée pour les analphabètes fonctionnels risque de ne pas être utilisée puisqu'elle peut être perçue comme étant stigmatisante et certains utilisateurs peuvent avoir honte de l'utiliser (Knoche et Huang, 2012). Le développement d'une interface accessible commencerait donc par la modification de sites actuels plutôt que de créer des versions exclusives tout en considérant l'expérience de l'ensemble des utilisateurs.

1.1 Questions de recherche

L'objectif du présent mémoire est d'améliorer l'accessibilité des interfaces bancaires numériques pour les analphabètes fonctionnels tout en s'assurant que l'expérience des autres utilisateurs ne soit pas compromise. La séance expérimentale comportait deux parties avec leur propre design expérimental ainsi que leur propre question de recherche. Cependant, l'objectif restait le même pour les deux articles.

Pour l'article 1, en plus d'améliorer l'accessibilité, un autre objectif était d'évaluer les processus neurophysiologiques des mots et des icônes chez des analphabètes fonctionnels et des sujets avec un niveau de littératie normal. Les participants devaient donc effectuer une tâche de recherche visuelle avec ces deux types de stimuli et leur performance ainsi que leur activité corticale, mesurée par électroencéphalographie (EEG), étaient évaluées. Cet article permettait de répondre à la question suivante :

QR1 : *Est-ce que les représentations iconographiques sont efficaces pour améliorer l'accessibilité des interfaces bancaires chez une population d'analphabètes fonctionnels ?*

Pour l'article 2, l'objectif était seulement d'améliorer l'accessibilité des interfaces bancaires numériques pour les analphabètes fonctionnels. Un prototype d'une version simplifiée d'un vrai site bancaire a été créé en réduisant le nombre de calls-to-action (CTAs) afin de diminuer les risques de surcharge de choix (« choice overload »). Les participants, qui étaient des analphabètes fonctionnels et des sujets de contrôle avec un niveau de littératie normal, devaient effectuer diverses tâches bancaires sur les deux interfaces afin de comparer leurs expériences sur ceux-ci. Leur performance ainsi que leur niveau d'effort durant les tâches, mesurées en partie avec le EEG, étaient évalués. Cet article permettait de répondre à la question suivante :

QR2 : *Dans quelle mesure la réduction de la densité des choix sur une interface numérique affecte-t-elle l'expérience des analphabètes fonctionnels par rapport aux utilisateurs généraux ?*

1.2 Objectifs et contributions

L'objectif de ce mémoire est de déterminer comment améliorer l'accessibilité des interfaces bancaires numériques pour une population d'analphabètes fonctionnels sans nuire à l'expérience du reste de la clientèle. Des contributions théoriques et pratiques sont attendues des études dans le présent mémoire.

D'une part, concernant les contributions théoriques, les articles devraient approfondir les connaissances sur le traitement neurophysiologique de l'information visuelle des analphabètes fonctionnels, et ce, avec différents stimuli : dans l'article 1, les mots et les icônes lors d'une tâche de recherche visuelle contrôlée, et dans l'article 2, l'information visuelle présente sur de vraies interfaces bancaires numériques lors de l'accomplissement de tâches bancaires. Aussi, l'article 2 devrait éclaircir l'effet d'une réduction du nombre de choix d'une interface (calls-to-action), dans le but de diminuer les risques de surcharge de choix (« choice overload »), sur l'expérience des analphabètes fonctionnels et d'un groupe contrôle. Une meilleure compréhension de ces processus neurophysiologiques ainsi que de l'effet d'un design alternatif pourrait permettre de guider le développement d'interfaces mieux adaptées aux besoins d'une population analphabète fonctionnelle.

D'autre part, concernant les contributions pratiques, les articles de ce mémoire devraient offrir des connaissances sur les éléments d'une interface bancaire (les icônes, le nombre de choix, etc.) ainsi que les facteurs pouvant contribuer à améliorer l'expérience utilisateur des analphabètes fonctionnels. Ces pratiques peuvent s'appliquer non seulement au milieu bancaire, mais potentiellement à d'autres services essentiels, réduisant ainsi le fossé numérique.

1.3 Présentation de l'article 1

Le premier article a été accepté à la conférence « 2024 NeuroIS retreat » et a été présenté le 11 juin 2024. L'article se nomme « Comparing the Visual Processing of Words and Icons for Functional Illiterates in an Online Banking Context » et les co-auteurs sont les suivants : Jared Boasen, Yasmine Maurice, Constantinos Coursaris, Sylvain Sénécal et Pierre-Majorique Léger. Cet article utilise les données collectées lors d'une des deux parties de la séance d'expérimentation. Dans cette partie, les participants devaient effectuer une tâche de recherche visuelle avec des mots et des icônes. Ceci était dans le but de mesurer l'activité corticale des participants lors d'une tâche contrôlée afin de pouvoir déterminer plus justement les processus cognitifs utilisés lors du traitement des stimuli visuels.

1.3.1 Résumé

Les analphabètes fonctionnels représentent une partie importante de la population et ont besoin d'interfaces accessibles. Les icônes, parmi d'autres éléments d'interface, sont un élément de conception souvent utilisé pour améliorer l'accessibilité. Cependant, les preuves neurophysiologiques de leur efficacité chez les analphabètes fonctionnels restent rares. Lors d'une expérience contrôlée avec des stimuli venant d'un site bancaire en ligne, cette étude a utilisé des mesures EEG et comportementales pour évaluer objectivement l'efficacité des icônes par rapport aux mots chez des sujets avec un niveau de littératie normale et des analphabètes fonctionnels. Les résultats montrent que les icônes par elles-mêmes peuvent ne pas être suffisantes pour améliorer l'accessibilité puisque leur nature abstraite peut nuire à leur interprétation.

1.4 Présentation de l'article 2

Le deuxième article est en préparation d'être soumis au journal « International Journal of Human-Computer Interaction ». L'article se nomme « Can Reducing Choice Overload Improve the Accessibility of Online Banking Interfaces for Functional Illiterates? » et les co-auteurs sont les suivants : Jared Boasen, Yasmine Maurice, Constantinos Coursaris, Sylvain Sénécal et Pierre-Majorique Léger. Cet article utilise les données collectées lors d'une des deux parties de la séance d'expérimentation. Dans cette partie, les participants devaient accomplir diverses tâches bancaires sur un vrai site bancaire ainsi que sur un prototype d'une version simplifiée de cette interface. Ceci était dans le but d'évaluer l'expérience sur l'interface simplifiée et déterminer si une réduction de la densité de choix pouvait améliorer l'accessibilité du site pour les analphabètes fonctionnels.

1.4.1 Résumé

Dans les pays développés, il existe une forte prévalence d'analphabètes fonctionnels qui ont besoin d'interfaces accessibles pour plusieurs services essentiels comme les services bancaires en ligne. La présente étude vise donc à améliorer l'accessibilité des interfaces bancaires numériques pour les analphabètes fonctionnels sans compromettre l'expérience utilisateur de l'ensemble de la clientèle. En réduisant le nombre d'éléments « call-to-action » (CTA), une version simplifiée d'une vraie interface bancaire numérique a été développée et testée. Un groupe d'analphabètes fonctionnels et un groupe de contrôle avec un niveau de littératie normal ont effectué trois tâches bancaires sur chaque version de l'interface. Des mesures de performance (temps de complétion et taux de succès) et d'effort (échelle auto-déclarée et EEG) ont été recueillies. Les résultats ont montré que les analphabètes fonctionnels avaient globalement de moins bonnes performances, mais aucune différence significative n'a été détectée entre l'interface simplifiée et l'interface actuelle. Cependant, les résultats de l'EEG ont montré des différences dans le patron d'activité cérébrale entre les groupes pour toutes les bandes de fréquence d'intérêt (thêta, alpha et bêta). Ces résultats suggèrent que la réduction de la densité de choix n'a pas d'impact significatif sur l'accessibilité d'une interface pour les analphabètes fonctionnels. Toutefois, il peut être plus efficace d'améliorer la familiarité générale avec les informations visuelles d'une interface et les étapes nécessaires pour accomplir des tâches importantes. De prochaines études pourraient explorer l'effet de diverses méthodes d'accueil pour améliorer l'accessibilité.

1.5 Structure du mémoire

Dans ce mémoire, il y a quatre chapitres. Le premier est l’introduction où le contexte et les objectifs sont présentés. Il contient aussi un résumé des études qui ont été conduites dans le cadre de ce mémoire.

Le chapitre suivant contient l’article 1 qui décrit une expérience en laboratoire où les participants devaient accomplir une tâche de recherche visuelle avec des mots et des icônes. Ceci était dans le but de tester les processus neurophysiologiques impliqués dans le traitement de ces deux types de stimuli et déterminer si les icônes sont efficaces pour améliorer l’accessibilité des interfaces bancaires numériques chez les analphabètes fonctionnels.

Le chapitre suivant contient l'article 2 qui décrit aussi une expérience en laboratoire. Cette fois-ci, les participants devaient accomplir des tâches bancaires sur deux versions d'un vrai site bancaire : la version actuelle avec une haute densité de choix et une version simplifiée avec basse densité de choix. La version simplifiée ayant été développée en réduisant le nombre d'éléments call-to-action (CTA), le but de l'étude était de tester comment une diminution de la densité de choix sur une interface bancaire numérique affectait l'expérience des analphabètes fonctionnels.

Le dernier chapitre est la conclusion où sont résumées les trouvailles principales ainsi que les implications théoriques et pratiques venant des études qui ont été conduites. Les limites des études et les possibilités de recherche futures y sont aussi discutées.

Il est à noter que chaque article contient sa propre liste de références et qu'à la fin du mémoire se trouve une liste de référence générale.

1.6 Contributions et responsabilités individuelles

Le tableau suivant contient une description des contributions de l'étudiant ainsi que des étapes qui ont été entreprises pour l'accomplissement du mémoire. Pour toutes les étapes, le pourcentage de contribution est indiqué à chaque tâche. Il est à noter que cette valeur ne prend pas en compte les commentaires des co-directeurs de ce mémoire.

Tableau 1.

Contribution de l'étudiant durant les étapes du projet

Étapes	**Tâches et contributions de l'étudiant**
Développement des questions de recherche	Identification des points inexplorés dans la littérature – **100%** Définition de la problématique – **100%** Définition des questions de recherche – **100%**
Revue de la littérature	Recherche, lecture et évaluation des articles – **100%**

Conception de l'expérience	Développement des stimuli – **60%** - Création du prototype des interfaces (fourni par le partenaire industriel) - Sélection des stimuli - L'équipe de recherche s'est occupée du 40% restant Développement du protocole expérimental – **80%** - Développement des tâches. - Sélection des échelles de mesure. - L'équipe de recherche s'est occupée du 20% restant. Application au comité d'éthique – **100%** - Préparation des différents documents et formulaires.
Recrutement des participants	Recrutement des participants – **40%** - Présentation du projet chez la fondation d'alphabétisation - L'équipe de recherche s'est occupée du 60% restant
Prétests et collecte de données	Gestion des prétests et de la collecte de données – **100%** - En collaboration avec l'équipe de recherche.
Analyse des données	Extraction des données – **100%** Nettoyage des données – **100%** Analyse des données – **90%** - L'équipe de recherche et le statisticien du Tech3Lab se sont occupés du 10% restant.
Écriture du mémoire	Écriture du mémoire – **100%** Écriture de l'article 1 – **90%**

	- Les co-auteurs se sont occupés du 10% restant. Écriture de l'article 2 – **100%**

Chapitre 2 : Article 1
Comparing the Visual Processing of Words and Icons for Functional Illiterates in an Online Banking Context*

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Abstract. Functional illiterates make up a significant portion of the population and need accessible interfaces. Icons, among other interface elements, are a design consideration that is often used to improve accessibility. However, neurophysiological evidence on their effectiveness in functional illiterates remains scant. In a controlled experiment based on online banking stimuli, this study used EEG and behavioral measures to objectively evaluate the efficaciousness of icons compared to words in literate and functional illiterate subjects. Results show that icons alone might not be sufficient to increase accessibility because their abstract nature can hinder their interpretation.

Keywords: functional illiteracy · visual search · EEG · accessibility

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2.1 Introduction

Large-scale literacy assessments have revealed that in developed countries there is a high prevalence of functional illiteracy [1], defined as an insufficiency in reading, writing, counting and other skills, like digital literacy, necessary to function in society [1,2,3]. As businesses across domains increasingly shift towards digital tools and interfaces [4,5,6], there is a major need to make these interfaces accessible for those with functional illiteracy.

Using pictographic symbols such as icons over words is a well-known approach to improve accessibility through improved visual affordance [7,8,9,10]. Visual affordance is defined as visual cues that help users quickly identify and understand the functions of elements (e.g., a shopping cart icon affords a user instantly comprehensible knowledge regarding where items they have selected for purchase can be found). Digital interface designers have increasingly incorporated icons to improve visual affordance in many domains, including banking [11,12] to make the overall navigation experience easier. Although functional illiterates have functional visual ability, reports indicate numerous cognitive shortcomings in visual short-term and long-term memory and even listening ability compared to literates [13,14]. Moreover, neurophysiological evidence suggests that illiteracy is accompanied by decreased interhemispheric connectivity and connectivity between early visual and higher-order language processing areas [15,16]. Thus, whether icons improve visual affordance over text for functional illiterates is questionable, and cognitive and neuroimaging studies addressing this issue remain scant.

The reduced short-term memory capacity and connectivity between early visual areas and higher-order language processing areas suggest that the visual affordance of icons over text could be assessed in functional illiterates via neurophysiological indices of higher-order processing and semantic processing. The prefrontal cortex is often implicated in higher-order processing, and past research suggests that increased prefrontal electroencephalographic (EEG) beta activity is associated with less efficient higher-order processing during visual search and target identification [17,18,19,20,21]. Meanwhile, studies have observed the role of theta oscillatory activity in semantic processing, with a positive association between theta amplitude and semantic processing load [22,23].

Thus, building upon our past work on EEG-based accessibility research [24,25,26], the present study empirically tested the neurophysiological processing of icons and words in functional illiterate and literate subjects during a visual search task using EEG indices of beta and theta power. Given the past accessibility evidence on icons over text, we hypothesized that while functional illiterate subjects may exhibit reduced semantic processing ability in association with increased higher-order processing demands compared to literate subjects regardless of stimulus type, functional illiterate subjects would nevertheless exhibit reduced higher-order processing demands for icons compared to words.

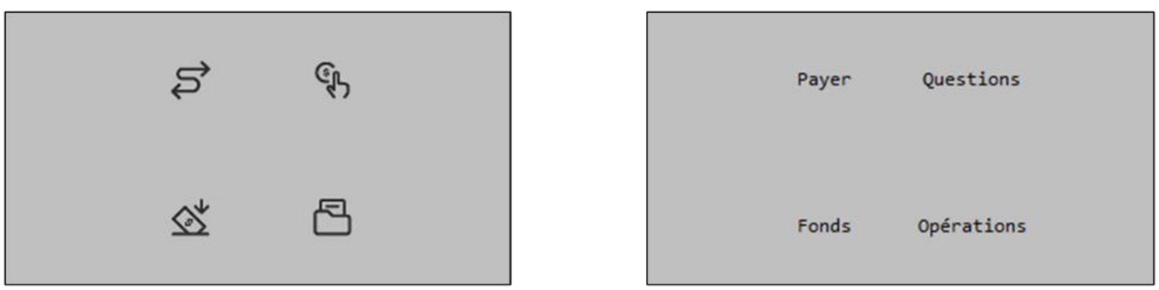
2.2 Materials and Methods

This study targeted 25 right-handed subjects, 14 with functional illiteracy (hereafter: experimental group) (mean age ± SD: 57.14 ± 10.11 yrs, 12 F and 2 M), and 11 normal healthy control subjects (mean age ± SD: 41.09 ± 11.95 yrs, 5 F and 6 M). The experimental group's participants were recruited through two non-profit literacy organizations which aid functional illiterates. The participants of the control group were recruited by an external recruitment agency. All reported no neurological or psychiatric diagnosis and provided oral (for the experimental group) or written (for the control group) informed consent before participation [27]. The study was approved by our institution's ethical review board.

The experiment was a visual search task presented in two 48-trial blocks of either word or icon stimuli. Each trial comprised four stimuli with one target and three distractors. Block and trial order, as well as target stimulus position, were randomized. All stimuli were chosen by the research team and came from actual banking interfaces. For each block, there was a pool of 12-word targets or 12-icon targets, each appearing four times per block and a pool of 30 distractors (words or icons). Before each trial's presentation, subjects were orally instructed to perform an action related to a real-life online banking task (Figure 1) and then instructed to select the most appropriate visual target from the subsequent four presented that would allow them to complete that task. Participants had a maximum of 20 seconds to decide.

Thirty-two channel EEG (actiCap, BrainProducts, GmbH, Munich, Germany) was recorded raw at a 500 Hz sampling rate using BrainVision Recorder (BrainProducts, GmbH, Munich, Germany). EEG data was cleaned and processed in Brainstorm similar to [28], with envelope-related potentials computed using Hilbert transform in the theta (5-7 Hz) and beta (15-29 Hz) bands and averaged across trials and then from 0-2s relative to stimulus onset and then normalized as a percent deviation from baseline.

Behavioral differences in response time and accuracy were analyzed using Wilcoxon signed-ranked tests for within-subject comparisons of stimulus type and Wilcoxon sum rank test for between-group comparisons. For the EEG data, repeated measures (RM) ANOVA was performed separately for the theta (5-7 Hz) and beta (15-29 Hz) bands to evaluate the effects of the independent variables: Group (2), stimulus type (2) and channel (32 channels). In the case of significant effects or interactions, pairwise comparisons were performed. Multiple comparisons were corrected using Bonferroni for behavior and Holm for EEG. Holm correction was chosen for EEG instead of Bonferroni because the latter is known to be too conservative in situations involving numerous comparisons as encountered with the channel variable [29]. The threshold for significance was set at $p < 0.05$.



Trial example with icons

Trial example with words

Fig. 1. Examples of icon (left) and word (right) trials. English translations of words are (clockwise from upper left): Pay, Questions, Operations, and Funds. For both examples, the instruction that was presented to the participant was: “You want to pay a bill or your credit card; Choose the icon/word that seems most appropriate to achieve your goal”.

2.3 Results

Response time was significantly different between groups (p = 0.0015), with longer response time in the experimental group (5.93 ± 2.11 s) than in the control group (2.42 ± 0.73 s), regardless of stimulus type. Pairwise comparisons indicated the significance of this effect to be stronger for words (p_{corr} = 0.001) than icons (p_{corr} = 0.028), suggesting a possible interaction. However, there was no significant main effect of stimulus type (mean icons ± SD: 3.63 ± 1.73 s, mean words ± SD: 3.99 ± 2.39 s, p = 0.094).

Accuracy was significantly different between groups (p = 0.002), with higher accuracy in the control group (84.19 ± 9.02 %) than in the experimental group (55.33 ± 21.01 %). Pairwise comparisons indicated this effect to have similar significance levels for icons (p_{corr} = 0.002) and words (p_{corr} = 0.004). Meanwhile, there was a significant effect of stimulus type (p = 0.003). Pairwise comparisons revealed this to be driven by the control group, who were significantly more accurate with words than icons (0.90 ± 0.05 vs. 0.78 ± 0.08, p_{corr} = 0.015), whereas accuracy was not significantly different between words and icons for the experimental group (0.63 ± 0.23 vs. 0.47 ± 0.15, p_{corr} = 0.201), though it did trend lower. Notably, standard deviation of accuracy was two to four times higher in the experimental group than the control group.

RM ANOVA of theta (5-7 Hz) activity revealed a significant effect of channel ($F_{(31, 984)}$ = 10.10, p < 0.001), but no significant effect of group ($F_{(1, 984)}$ = 0.44, p = 0.506) nor stimulus type ($F_{(1, 984)}$ = 1.45, p = 0.229), nor interaction between group and stimulus type ($F_{(1, 984)}$ = 1.50, p = 0.221) nor interaction between stimulus type and channel ($F_{(1, 984)}$ = 0.17, p = 1). However, there was a significant interaction between group and channel ($F_{(31, 984)}$ = 1.92, p = 0.002), with a pattern of lower theta activity in the experimental group compared to the control group primarily concentrated over left posterior-occipital electrodes. These differences did not reach significance at any specific electrode, as per pairwise comparisons (see Figure 2 left).

RM ANOVA of beta (15-29 Hz) indicated a significant effect of stimulus type ($F_{(1, 967)}$ = 4.51, p = 0.034), with higher average beta activity for words (-8.47 ± 37.91 %) than with icons (-12.01 ± 34.02 %). There was also a significant effect of channel ($F_{(31, 967)}$ = 3.76, p < 0.001). However, there was no significant effect of group ($F_{(1, 967)}$ = 1.45, p = 0.229), nor interaction between stimulus type and group ($F_{(1, 967)}$ = 0.40, p = 0.525), nor group and channel ($F_{(1, 967)} = 1.21$, $p = 0.204$). Note that although the stimulus effect tended to be largest over frontal-temporal electrodes, the stimulus by channel interaction was not significant ($F_{(1, 967)} = 0.23$, $p = 1$), meaning that the pattern of beta activity across channels was similar for both stimulus types, and only differed by overall amplitude. (see Figure 2 right).

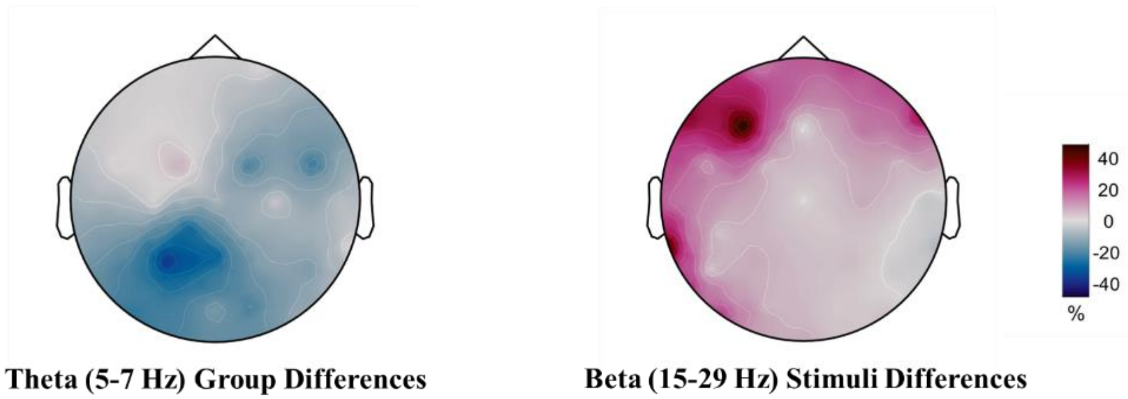


Fig. 2. EEG topography differences for theta (5-7 Hz) activity between groups (experimental group – control group) across all stimulus types (left), and beta (15-29 Hz) activity between stimulus type (words – icons) across groups. The key applies to both.

2.4 Discussion

Icons are often used when developing accessible digital interfaces. However, the neurophysiological impact of icons or words on the visual affordance of functional illiterates has scantly been researched. We aimed with this study to test the neurophysiological processing of icons compared to words during a visual search task and using EEG indices of beta and theta activity. We believed that, compared to words, icons should require lower higher-order processing demands for the experimental group, even if they may have reduced semantic processing ability compared to the control group across all stimuli. Although both icons and words demand semantic processing, functional illiterates still need more cognitive resources to interpret words because they have not developed efficient strategies related to reading such as the one for explicit phonological analysis [16].

As we hypothesized, the functional illiterate group had a poorer performance than the literate group with both words and icons. However, contrary to our hypothesis, this did not appear to be accompanied by increased higher-order processing, as beta activity was not significantly different between groups. Instead, neurophysiological differences between groups were observed in theta activity, primarily over posterior areas (Figure 2 left). Posterior theta activity has been recognized as sensitive to bottom-up visual processing and encoding [30], and lower theta activity over posterior-occipital areas has been previously observed during a visual recognition task for those with reading disorders compared to those without [31]. In conjunction with past reports that illiterates exhibit reduced cortical connections between visual and higher-order processing areas [14,15], the present theta results could be a sign of impeded visual information processing flow through early visual areas. However, the absence of beta-indexed higher-order processing between groups contradicts this. Instead, the lower theta activity in functional illiterates may be more attributable to familiarity with the visual information. Indeed, in a study on word recall [32], word familiarity was positively related to recall accuracy and associated with increased occipital theta power. Given that functional illiterates have limited familiarity with not only words but also with icons which may appear on digital banking interfaces, it seems reasonable to consider that a general lack of familiarity with the visual stimuli used in the present study may have impeded bottom-up visual processing, thereby underlying our observed theta results.

Meanwhile, there was a significant reduction in beta activity, regardless of group, when searching for icons compared to words (Figure 2 right). This suggests icons required less higher-order processing than words [16]. This is aligned with studies which have suggested that visual affordance is associated with reduced cognitive demands [33,34] and thus indicates icons improved visual affordance over words in the present study. However, and surprisingly, both groups exhibited lower accuracy with icons than with words, and significantly so for literates. Furthermore, that this result did not reach significance in functional illiterates may be less attributable to icons and words provided comparable visual affordance, and more related to the much higher standard deviation in accuracy for icons or words in functional illiterates compared to literates. In short, whatever benefit icons provided over words in increasing visual affordance, it was ultimately offset by a loss of accuracy during their interpretation.

There were some limitations regarding the present study and analyses. First, time constraints prevented formal literacy level assessments, which could have aided in controlling intra-group heterogeneity. Nevertheless, behavioral results for the word task yielded convincing evidence of reduced reading ability in the experimental group. Second, the present analyses did not consider the time domain. Further analyses should explore differences in event-related responses between groups.

In sum, icons alone are not enough to improve the accessibility of an interface in any population. Indeed, rather than focusing solely on changing the visual design, our results suggest that increasing general familiarity with the interface’s relevant visual information may be a crucial step toward improving interface accessibility in functional illiterate populations. Here, online, or in-person tutorials (e.g., workshops) could be an effective way of achieving this.

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Chapitre 3 : Article 2
Can Reducing Choice Density Improve the Accessibility of Digital Banking Interfaces for Functional Illiterates?*

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Abstract: There is a high prevalence of functional illiterates in developed countries that need accessible interfaces for several essential services including online banking. The present study aimed to improve the accessibility of digital banking interfaces for functional illiterates without compromising the user experience of the overall customer base. We hypothesized that reducing the choice density of a digital banking interface would improve the general task experience for functional illiterates. By reducing the number of calls-to-action (CTAs) elements, a simplified version of a real online banking interface was developed and tested. Both a functional illiterate group and a literate control group completed three banking tasks on each version of the interface. Measures of performance (completion time and success rate) and effort (self-reported scale and EEG) were collected. Results indicated that functional illiterates had a worse performance overall, but no significant differences were detected between the simplified and actual interfaces. However, EEG results did show differences in the pattern of brain activity between groups for all frequency bands of interest (theta, alpha, and beta). These findings suggest that reducing the choice density does not significantly impact the accessibility of an interface for functional illiterates. Instead, improving general familiarity with an interface's visual information and the steps necessary to complete important tasks may be more effective.

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Future studies could explore the effect of various onboarding methods to improve accessibility.

Keywords: Accessibility, Functional illiteracy, Choice density, User Experience, EEG

3.1 Introduction

There are about 763 million people worldwide who are unable to read or write (UNESCO, 2024). In developed countries, however, there is a higher prevalence of functional illiteracy, which not only involves difficulty in reading and writing but encompasses a broad array of deficiencies in skills necessary to function in society properly (Vágvölgyi et al., 2016). This includes numerical abilities and digital literacy, the ability to use digital platforms and software (Lo Prete, 2022), which are needed to accomplish important tasks such as filling out a job application and using a computer for online banking (Cree et al., 2012; Mohammed et al., 2023a; Vágvölgyi et al., 2016). An inability to perform these tasks can therefore negatively impact one's social and economic integration in today's modern society, increasing the digital divide (Ahmed et al., 2019).

Banking is a domain that can be particularly challenging for the functional illiterate population. As many modern businesses do, banks increasingly shift towards a digitalization of their services as seen with the availability and use of mobile apps (Chuard, 2020). According to Valenti and Alderman (2021), this change not only comes from a desire to keep up with the competition from other industries but also to respond to consumer's growing preference for digital banking tools. For example, 76% of consumers prefer using digital tools for transferring funds and 80% for paying bills. Notably, because of their reading difficulties, it is unlikely that functional illiterates participate in companies' surveys conducted to gather channel preferences. Since most digital interfaces rely heavily on text with specialized vocabulary, this design aspect is often an important usability barrier for a functional illiterate population (Capra et al., 2012; Islam et al., 2023; Medhi et al., 2006). Additionally, digital banking interfaces involve several features (e.g., arithmetic notation and modern iconography) that require an adequate level of literacy and education to be understood (Matthews, 2019). This uncertainty may lead to abandonment during tasks especially since money is involved because the risk of loss is higher. It becomes essential then to improve the accessibility of online banking interfaces to reduce the digital divide between the functional illiterates and the rest of the population (Ahmed et al., 2019; Chandry et al., 2012).

Many approaches have been developed and studied to improve the usability and accessibility of both digital and non-digital interfaces for the benefit of all users. One of the most common methods across all types of user interfaces (UIs) is using iconographic elements such as icons. These elements are visual representations based on culturally accepted and understood representations of concepts, similar to metaphors (Huang et al., 2015; Roberts et al., 2023), that help improve communication with users (Engelbart and English, 1968; Islam et al., 2020). In human-computer interaction (HCI), icons are designed to symbolize abstract or complex concepts in a simplified and easily recognizable manner that can potentially bypass the need for reading text (e.g. the use of a trash can to indicate the location of deleted items). As metaphors, icons can help make interfaces more intuitive by aligning the visual information with users' prior knowledge and mental models (Carroll & Thomas, 1982). This alignment also reduces cognitive load and facilitates navigation which improves the general user experience. Icons have been applied in a variety of fields such as medicine (Katz et al., 2006) and computer systems (Isherwood, 2009). In banking, they have also been used to help improve the accessibility of interfaces for an illiterate population (Islam et al., 2023).

However, studies have found that for both functional illiterates and the general population, a lack of familiarity with the context of icons can hinder their efficacy, as their interpretation is very susceptible to cultural biases and personal experience (Thatcher et al., 2006; Wiedenbeck, 1999). Matthews (2019) mentions a case where a group of illiterate adults in rural India were very confused by the various digital banking icons they were testing and could not recognize the significance of symbols such as the arrow or "+" sign. Text-free interfaces have also been previously tested with semi-illiterate and illiterate participants (Islam et al., 2023). An example of this is Medhi et al. (2006) who, through the design and testing processes of two interfaces, suggested many design features that could be helpful for this population such as graphical icons (especially semi-abstracted icons), voice feedback and minimal text. Digital voice particularly can be seen as the most adequate tool to improve inclusion.

However, building a software or interface specifically for functional illiterates can be perceived as stigmatizing and may lead to low use as seen with an adapted Motorola phone for people with low literacy (Knoche & Huang, 2012). Combined with the fact that a good accessible design considers the experience of the entire customer base, there is an argument to be made for improving existing pages instead of creating exclusive interfaces for a subgroup of users. Consequently: Is it possible to improve the accessibility of a digital banking interface for a functional illiterate population while ensuring that the user experience of the general user remains uncompromised?

Previous studies have found that functional illiterates tend to be easily overwhelmed when exposed to a higher number of options both in a physical (e.g., a large number of products in a store) (Viswanathan et al., 2005) and a digital environment (e.g., a large number of options in the navigation bar) (Chaudry et al., 2012). This could be due to neurophysiological differences, both physical and structural, affecting numerous cognitive functions such as reduced working memory and attentional capacity (Ardila et al., 2010; Bulajić et al., 2019; Vágvölgyi et al., 2016; van Linden & Cremers, 2008). These cognitive shortcomings suggest that functional illiterates are more susceptible to choice overload which is a phenomenon that occurs when the number of options to consider during decision-making exceeds the individual's cognitive resources resulting in decision-making difficulties and lower choice satisfaction (Jacob et al., 2024). Choice overload can also be present in digital environments and be influenced by the user interface (UI) layout and the number of options (Jacob et al., 2024; Starke et al., 2022). Therefore, the present study aims to answer the following research question:

RQ: *To what extent does reducing choice density on a digital interface affect the experience of functional illiterates compared to the general user?*

To lower choice density, we designed a simplified version of a real digital banking interface by reducing the number of calls-to-action (CTAs) (e.g., buttons). We then evaluated the experience of participants, who came from a functional illiterate (low literacy group) and control population (literate group), on the simplified interface (lower choice density) and compared it with their experience on the actual banking interface (higher choice density). The evaluation was done by having them complete three banking tasks on each interface. Participants' performance, reflected in completion time and success rate, as well as effort, reflected in a self-perceived effort measure, were recorded during the tasks.

As an additional measure of effort, cortical activity was also recorded during the experiment using electroencephalography (EEG) with theta (5-7 Hz), alpha (8-12 Hz), and beta (15-29 Hz) being frequency bands of interest (Antonenko et al., 2010). We expected that participants with low literacy (i.e., functional illiterates) would have an improved experience on the lower choice density interface (lower completion time, higher success rate, and lower effort). We also expected that the low literacy group would have a worse performance and would need more effort during the tasks than the literate group regardless of the interface type.

Results show that the low literacy group performed worse (higher task completion time and lower task success rate) and reported higher effort than the literate group regardless of the interface type. However, no significant effect of the choice density on performance or effort was detected. Additionally, although no significant main effects of literacy or choice density on the EEG activity were detected, there was a significant group by channel interaction effect detected for all frequency bands of interest suggesting significant differences in the pattern of brain activity between groups for theta, alpha and beta frequencies.

These findings suggest that functional illiterates' lack of familiarity with online banking may explain the performance differences between groups. They also suggest that familiarizing users with an interface's important information or functionalities might be more effective in improving accessibility than focusing on altering the visual design, such as by lowering the choice density. The present study should contribute to the current accessibility literature as well as the understanding of neurophysiological processes in functional illiterates.

3.2 Background literature

3.2.1 Literacy

Functional literacy has an essential role in accomplishing many everyday tasks: Accessing bank accounts, reading medication labels, etc. Lack of literacy can hinder social inclusion and personal development because it involves many crucial abilities. According to UNESCO (2024), literacy is a continuum of skills in reading, writing and numeracy (calculation skills) that are part of a larger set of skills, which is a definition many authors would agree with (Vágvölgyi et al. 2016). The lack of literacy also impacts other skills that need some reading, writing and counting abilities, such as financial literacy and digital literacy that are necessary to function independently in society. Lo Prete (2022) provides a definition of those two types of literacy: Financial literacy is defined as the ability to understand enough economics and finances to be able to make decisions on one's personal finances; digital literacy is the ability to use digital tools and platforms. Because of their nature, both digital and financial literacy are important to be able to use online banking tools such as banking websites. However, it is important to note that those skills that are influenced by one's literacy are still separate constructs from it (Baskakova & Soboleva, 2019; Lusardi, 2015; Nedungadi et al., 2018). Some people with low levels of literacy can be proficient with finances, just like some can be comfortable with digital tools. This adds to the challenge of defining what makes someone a functional illiterate as it involves much more than reading and writing. It has been suggested that multiple sub-groups with different difficulties (e.g. reading and calculation) may exist within this group (Vágvölgyi et al., 2016).

Additionally, as mentioned, literacy is a continuum and is often represented by five levels of literacy (van Linden and Cremers, 2008). Levels one and two represent a severe lack of literacy. A functional illiterate person, who does not have the appropriate levels of literacy and numeracy skills to properly function in society, would be of level two and below. Level three is seen as the benchmark for functional literacy where one's literacy skills are considered sufficient to properly function in society. At levels four and five a person is literate. This distinction between levels could also be reflective of the heterogeneity of this population. Indeed, not every functionally illiterate person might be on the same level of literacy (level 1 or 2), and this could be an important consideration when designing and testing accessible interfaces. However, Vágvölgyi et al. (2016) suggest that there should be less variability in the language-related skills of functional illiterates than in illiterates.

Some important distinctions also need to be made about illiteracy and functional illiteracy. According to Vágvölgyi et al. (2016), an illiterate person is someone who has not learned how to read or write a single word in any language. Functional illiteracy involves the application of those skills i.e., whether they can be used to accomplish tasks. Also, illiteracy results from a lack of education rather than a neurological issue, mental disorder or other problem (impaired speech, hearing or vision). Although it often comes with similar difficulties as dyslexia and dyscalculia, pure functional illiteracy is still separate from these conditions.

3.2.2 Consequences of low literacy

Gaining literacy has been known to change the brain structurally and many studies comparing illiterates and literates support this finding (Dehaene et al., 2010; Dehaene et al., 2015; Vágvölgyi et al., 2016). For example, structural brain scans and fMRI studies have shown decreased interhemispheric connectivity but also decreased connectivity between language processing regions including those between higher-order and early visual processing areas. With those structural differences, illiterates also have different cognitive abilities (Vágvölgyi et al., 2016). One of these differences is on working memory where functional illiterate participants had more difficulties in working memory tasks than literate participants which can hinder their ability to process visual information (Dehaene et al., 2015; Vágvölgyi et al., 2016). This makes sense since studies have shown that low literate people have deficits in different components related to visual working memory (Gazzaley and Nobre, 2011; Harrison and Tong, 2009): Early visual processing (perception), attention, and executive functions (Ardila et al., 2010; Dehaene et al., 2015; Vágvölgyi et al., 2016; van Linden and Cremers, 2008).

Because functional illiterates lack proficiency in many abilities, this group has difficulty accomplishing tasks that may be easier for literate people. Many studies show that functional illiterate or illiterate participants tend to have poorer performance, reflected in higher completion time and lower success rates, and higher perceived effort during various cognitive and UX tasks compared to literate participants (Bramao et al., 2007; Mohammed et al., 2023b; Vágvölgyi et al., 2016; Viswanathan et al., 2005). Similar complications can be seen in day-to-day life where tasks can take much longer to accomplish as they take time to properly process the visual information. However, if time is limited due to social pressures or embarrassment in asking for help, then wrong decisions can be made leading to a higher risk of abandonment or mistakes during the task (Matthews et al., 2019; Viswanathan et al., 2005). Limited understanding also results in tasks being perceived as more difficult. In fact, functional illiterates tend to use more cognitive resources to accomplish tasks than literates.

Despite those difficulties, functional illiterates have found strategies to work through life and use digital interfaces. When navigating their cellphone, Knoche and Huang (2012) have found, through semi-structured interviews conducted with 9 participants, that functional illiterates use rote memorization, which is the memorization of patterns of actions (e.g., select the third icons from right, scroll up once and click the phone icon on the second contact). This allows them to achieve a task (e.g., calling a friend) without needing to read any textual information such as names or labels. For this process, icons as well as words' appearance such as length and shape can be used as landmarks and help with users to orient themselves within the interface. Rote memorization was also used with other digital interfaces such as automated teller machines (ATMs). In another study comparing the behavior of functional illiterates to English-as-a-second language and poor, literate consumers, where unstructured interviews were used as well as observations during classroom activities in adult-education centers and a shopping task, the authors found coping strategies commonly used by functional illiterate customers (Viswanathan et al., 2005). For example, to reduce stress and cognitive demands, functional illiterates will often shop at the same store to limit unfamiliar environments, try to go to smaller stores to reduce variety and base their decision on a single attribute such as a lower price tag. The authors also found that functional illiterates tend to heavily rely on pictographic thinking which means they give literal meaning to pictorial elements (e.g., color, illustrations and words) instead of the abstract meaning that can be intended and treat symbolic information as images. In the shopping task, this was reflected in the assessment of a product's price (e.g., a bigger box would equal a greater cost) but also in the use of common symbolic information (e.g., product category, brand names, etc.) to navigate in the store. The authors pointed out that because of this reliance on pictographic thinking, an alteration in the environment can lead to confusion and they gave an example of a participant that took longer to find a product in an unfamiliar store which made him more nervous. These behaviors suggest that habit and familiarity seem to be important factors in the coping strategies used by a low-literate population.

3.2.3 Effort

Cognitive load is a multidimensional construct that represents the load on an individual's cognitive system while they are performing a task (Paas et al., 2003). In addition to having a causal dimension, it also has an assessment dimension as it is composed of measurable aspects: mental load, mental effort and performance. Among the three concepts, mental effort is the one considered to reflect actual cognitive load as it represents the quantity of cognitive resources allocated to respond to the demands of a task (Paas et al., 2003; Zhu et al., 2021). In human-computer interaction (HCI), mental effort, and consequently cognitive load, can be assessed through self-reported scales, such as the Customer Effort Score (Cuvillier et al., 2021; Dixon et al., 2010) and the NASA Task Load Index (Sweller et al., 2011), but also through neurophysiological tools.

Electroencephalography (EEG) allows for a non-invasive, continuous measure of effort as fluctuations in the activity of different frequency bandwidth, such as event-related synchronization (ERS) or desynchronization (ERD), can be indicative of how the mental state or cognitive processes are affected by a difficult task (Antonenko et al, 2010; Kumar and Kumar, 2016). Firstly, an increase in task demands is related to an increase in theta (5-7 Hz) activity (greater ERS) in the frontal midline region (Gomarus et al., 2006; Klimesch, 1999; Sauseng et al., 2010; Zhu et al., 2021). As theta is linked to information encoding and retrieval (memory), the load can be higher on these processes when a task requires more effort to complete. Secondly, alpha (8-12 Hz) activity tends to be suppressed (greater ERD) with increasing task demands (Clayton et al., 2018; Klimesh, 1999). Studies have found that it is due to an increase in attentional demands. Although alpha activity tends to be widespread with some concentration in the parietal region, localization can change depending on the nature of the task. For example, in visual tasks, where visual attention is required, alpha ERD is concentrated in the occipital region (Antonenko et al., 2010; Zhu et al., 2021). Finally, an increase in effort tends to also increase beta (15-29 Hz) activity (greater ERS) (Chikhi et al., 2022; Kumar and Kumar, 2016; Weiss and Mueller, 2012). Because beta is related to various cognitive processes, such as decision-making, higher-order linguistic functions and engagement, the location of the activity during difficult tasks tends to be uncertain, though studies suggest it to be in the frontal or temporal regions.

3.2.4 Choice overload

Choosing one option from a range of alternatives is the process of decision-making (Jacob et al., 2024). Although consumers tend to prefer larger assortments to choose from, there comes a moment when the number of options to consider is far greater than what an individual's cognitive capacities can handle. This phenomenon is called choice overload (Chernev et al, 2015; Jacob et al., 2024; Scheibehenne et al., 2010). Choice overload can then lead to many negative consequences: reduced satisfaction in one's selection, prolonged decision-making, increased decision-making difficulty, and more. It can also lead to increased cognitive load (Schneider et al., 2018) which can affect EEG activity (Antonenko et al, 2010; Kumar and Kumar, 2016) as described in the previous section.

The most direct method to reduce choice complexity is simply by reducing the number of alternatives available (Greifeneder et al., 2010; Jacob et al., 2024; Paquette & Kida, 1988). However, the negative relationship between the quantity of alternatives and satisfaction cannot always be assured as the specific condition in which large assortments cause choice overload remains unclear. Indeed, several factors have been suggested as moderators of the influence of assortment size and choice overload such as presentation style and task difficulty, though the literature has yet to come to a consensus (Chernev et al., 2015; Jacob et al., 2024; Scheibehenne et al., 2009). However, it has been shown through numerous studies that too many options will take a toll on a person's cognitive resources, especially with a functional illiterate population (Viswanathan et al., 2005), and therefore manipulating assortment size remains a viable option.

3.3 Hypothesis Development

In the present study, we sought to evaluate and compare the experience of two groups, a functional illiterate group with low literacy and a control group with literate participants, on two versions of an actual online banking interface: a simplified interface with lower choice density, and the current interface with higher choice density. Therefore, six hypotheses were developed to examine the effects of the literacy level of participants, the choice density of the interface, as well as the interaction between literacy and choice density on task performance and the effort needed to complete the tasks. The theoretical model of the present study is illustrated in Figure 1.

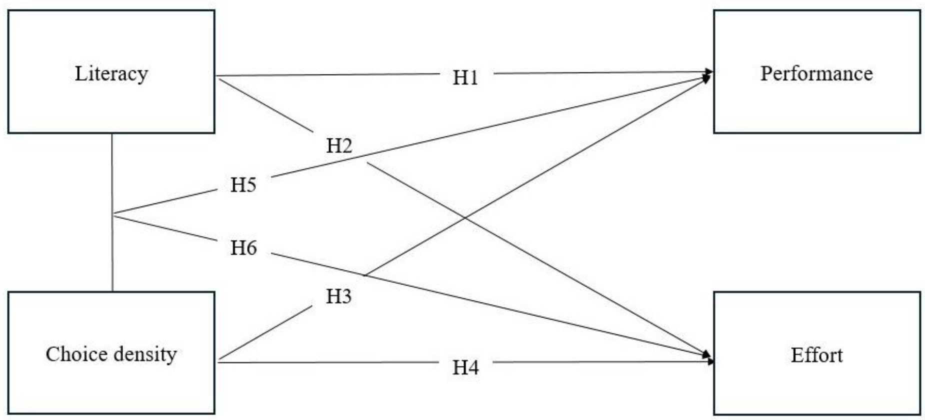


Fig. 1. Theoretical model of the present study.

As previously stated, functional illiterates face many challenges regarding the use of digital tools and interfaces that make task completion more difficult. They often require more time than the general user for the same task and may not always be as successful. Therefore, it is hypothesized that (H1) the participants with low literacy will have poorer performance during the tasks than the participants with a normal level of literacy, reflected in a higher completion time and lower success rate.

H1: *Participants with low literacy will have poorer performance during tasks than literate participants.*

As well as having performance issues during online tasks, functional illiterates also require more effort to complete them. Therefore, it is hypothesized (H2) that participants with low literacy will require more effort to complete tasks than literate participants, reflected in a higher self-reported effort as well as greater electroencephalography (EEG) theta and beta event-related synchronization and alpha desynchronization.

H2: *Participants with low literacy will require more effort to complete tasks than literate participants.*

As mentioned, choice overload happens when a user is presented with more options than they can process with their cognitive capacities. This can increase decision-making time and difficulty, which can affect task performance. Therefore, it is hypothesized (H3) that participants will have a better performance during tasks on the interface with a lower choice density than on the interface with a higher choice density, reflected in a lower completion time and higher success rate.

H3: *Participants will have a better performance during tasks on the interface with a lower choice density than on the interface with a higher choice density.*

Additionally, because choice overload takes a toll on a user's cognitive resources, task completion can also require more effort. Therefore, it is hypothesized (H4) that participants will require less effort to complete tasks on the interface with a lower choice density than on the interface with a higher choice density, reflected in a lower self-reported effort as well as lower EEG theta and beta event-related synchronization and alpha desynchronization.

H4: *Participants will require less effort to complete tasks on the interface with a lower choice density than on the interface with a higher choice density.*

Finally, concerning the interaction between the level of literacy and the choice density of the interface, although choice overload can affect the general user, it seems that functional illiterates are more susceptible to feeling overwhelmed when faced with a high number of options. They might suffer the consequences of higher choice density more easily than other groups: increased decision-making time, decision-making difficulty, and cognitive load. Therefore, it is hypothesized (H5) that participants with low literacy will show better performance during tasks using the interface with lower choice density compared to the interface with higher choice density, reflected in a lower completion time and higher success rate, in contrast to literate participants that will not show a significant difference in performance between the two interfaces.

H5: *Participants with low literacy will show better performance during tasks using the interface with lower choice density compared to literate participants.*

Also, it is hypothesized (H6) that participants with low literacy will require less effort to complete tasks using the interface with lower choice density compared to the interface with higher choice density, reflected in a lower self-reported effort as well as lower EEG theta and beta event-related synchronization and alpha desynchronization, in contrast to literate participants that will not show a significant difference in effort between the two interfaces.

H6: *Participants with low literacy will require less effort to complete tasks using the interface with lower choice density compared to literate participants.*

3.4 Methodology

The purpose of the present study was the examine the effect of reducing the choice density on a digital interface on the experience of both functional illiterates and the general users. A laboratory experiment was conducted to test the hypotheses by evaluating and comparing the experience of participants using both the actual as well as the simplified version of a real online banking interface. This section details the methodology used in this experiment.

3.4.1 Experimental design

A between-within-subjects 2 [low literacy vs literate] X 2 [lower choice density interface vs higher choice density interface] model was used for the experimental design. Here, low literacy refers to participants with functional illiteracy (hereafter known as the experimental group) while literate refers to the control subjects (hereafter known as the control group). Also, the higher choice density interface refers to the actual interface while the lower choice density interface refers to the simplified version.

A 90 second baseline was presented before the start of the experiment. Then, in total, participants had to complete six real banking tasks, three on each version of the interface. Real banking tasks were chosen as they allowed us to examine in a more ecologically valid way the impact of the experimental manipulation on the actions of users, their decision-making, and their overall experience. However, to maintain experimental control, the tasks were randomly presented as prototypes through a stimulus presentation software. At the end of each trial, participants were asked to rate their perceived effort during the task using an adapted 7-Point single item Likert scale.

3.4.2 Sample

For this study, 25 participants were recruited. In the experimental group, there were 14 participants (mean age ± SD: 57.14 ± 10.11 yrs, 12 F and 2 M). Defining and measuring functional illiteracy is complex, but it can also be as straightforward as adults who take part in adult literacy classes (Thompkins and Binder, 2003), though this method does have its shortcomings. According to Vágvölgyi et al. (2016), the accurate assessment of the literacy level of each person is often difficult and can lead to not properly differentiating functional illiterates from illiterates. The reason for attending such organizations can also be very different for each person as the literacy level and educational background can vary. Therefore, a homogeneous sample cannot be assured. However, it is very convenient from a recruitment perspective and that is why this method was used for the present study. Recruitment of the experimental group's participants was done in collaboration with two local non-profit literacy organizations that aid functional illiterates. A few weeks before data collection, members of our research team went to one of the foundation's meetings to present the study and tools used as well as answer all questions or concerns that foundation members may have had. People who were interested in participating would then notify the foundation manager so that their contact information and availability could be passed on to the research team. Because recruitment was difficult, we had to contact a second literacy foundation. Due to time constraints, we were unable to give a presentation of the study to this group of participants. However, the research team provided the proper explanations during the confirmation call 24 hours before the study and the day of the experiment. In the control group, there were 11 participants (mean age ± SD: 41.09 ± 11.95 yrs, 5 F and 6 M) that were recruited through an external firm.

For the experimental group, the inclusion criteria were initially: (1) be 18 years of age or older, (2) be able to speak and understand French, (3) attending a literacy foundation, (4) be right-handed and (5) able to work on a computer without glasses. However, because recruitment was difficult, criterion (5) was changed to: be able to work on a computer with normal or corrected vision with glasses. For the control group, inclusion criteria were: (1)

be 18 years of age or older, (2) be able to speak and understand French, (3) be a customer of this study's industrial partner, (4) be right-handed, and (5) able to work on a computer without glasses. For both groups, exclusion criteria were: (1) having a neurological or psychiatric diagnosis, (2) suffering or having suffered from epilepsy, (3) needing contact lenses, and (4) refusal to give consent.

Participants in the experimental group were given a compensation of CAD 250, while participants in the control group were given a compensation of CAD 200. The experimental group received higher compensation because the research team determined that functional illiterate participants might use more direct but more costly modes of transportation (e.g., taxi and Uber). This study was approved by the ethical review board of our institution (2023-5388).

3.4.3 Stimuli and Apparatus

In the actual online banking interface (higher choice density interface), there was a large number of buttons or calls-to-action (CTAs) that each represented a functionality of the website (e.g., messages, account settings, budget management) as shown in Figure 2. Among these 17 CTAs were three buttons that allowed participants to complete the first step of three out of the six experimental tasks, meaning that for each of these tasks on that interface, there was one target and 16 distractors in that specific region of the website. These 17 buttons were condensed to six in the simplified interface, reducing the number of choices available and therefore choice density (see Figure 3). On this lower choice density interface, two buttons allowed completing the other three tasks as two tasks shared the same button as a first step. For each of these tasks, in that region of the website, there was one target and five distractors.

To allow for comparison between both versions of the interface, three pairs of tasks of similar nature represented a type of task that would be done on a real online banking website: payment, transfer, and changing your password (a description of each task is available in Table 1). These six real banking tasks were chosen by the research team after a careful assessment to identify tasks that are commonly done on this online banking interface (for more details, see Table 1). This selection allowed for a more direct comparison between both versions of the interface and, as previously mentioned, the evaluation of the effect of the experimental manipulation.

In Task 1 (see Figure 4) and Task 3 (see Figure 6), participants were asked to do "payment" tasks where they had to pay a credit card bill on the higher choice density interface and a Netflix bill on the lower choice density interface, respectively. In Task 2 (see Figure 5) and Task 4 (see Figure 7), participants were asked to do "transfer" tasks where they had to do an e-transfer on the higher choice density interface and transfer money from their checking account to their savings account on the lower choice density interface. Finally, in Task 5 (see Figure 8 and 9) and Task 6 (see Figure 10 and 11), participants were asked to do "password change" tasks where they were asked to change the password of their online banking account on both the higher and lower choice density interfaces. The payment tasks (Task 1 and Task 3), as well as the transfer tasks (Task 2 and Task 4), were similar yet still distinct because the properties of the prototypes did not allow for the exact same tasks to be performed. However, because we sought to compare the interfaces and not the tasks, these variations would be accounted for during the analysis as both groups of participants would do them. That issue was not present for the tasks related to changing the password (Task 5 and Task 6) as they were available on both interfaces. Additionally, the amount of money manipulated during Task 1 to Task 4 (2$) could be considered unrealistic. This was considered not to be an issue because we wanted to compare the interfaces, and the tasks still allowed to effectively address the research question. Also, participants were made aware before the experiment that they might manipulate strange amounts of money.

As mentioned, tasks were displayed to participants as prototypes, for the experiment was developed and presented with the E-Prime 3 software (Psychology Software Tools, Pittsburgh, PA, United States), allowing for better experimental control. For each of them, only the buttons that allowed for the task's completion were active and this applied for each page of a trial. Although this reduces ecological validity, the selective activation of buttons ensured that all participants saw the same pages during the tasks allowing for a more robust comparison of groups as well as interfaces. Additionally, research assistants could note the amount of time a deactivated button was selected, which could help them decide when to help a participant move to the next step. The possible paths for completing the tasks were determined following an assessment by the research team. Participants could not scroll the page like a normal interface and had to click on “Up” and “Down” buttons on the right side of the screen to navigate vertically on the page (see Figure 2 and Figure 3). Participants were made aware of the characteristics of the prototype before they started the experiment.

After each trial, participants were verbally asked a question about their perceived effort during the task while both the question and scale were presented on the screen. Note that the format of the scale was adapted following recommendations made by experts in literacy (see Figure 12).

Table 1.

Description of the experimental tasks

Task	Task Type	Interface	Task Instructions
Task 1	Payment	Actual Interface	It's the end of the month and you must pay $2 on your credit card.
Task 2	Transfer	Simplified Interface	Your friend Felix lent you $2. Make an Interac transfer to pay him back.
Task 3	Payment	Actual Interface	It's the end of the month and you need to pay your $2 Netflix bill.

Task 4	Transfer	Simplified Interface	You've received your paycheck in your checking account and want to transfer $2 of that money to your savings account.
Task 5	Password change	Actual Interface	You want to change the password of your account.
Task 6	Password change	Simplified Interface	You want to change the password of your account.

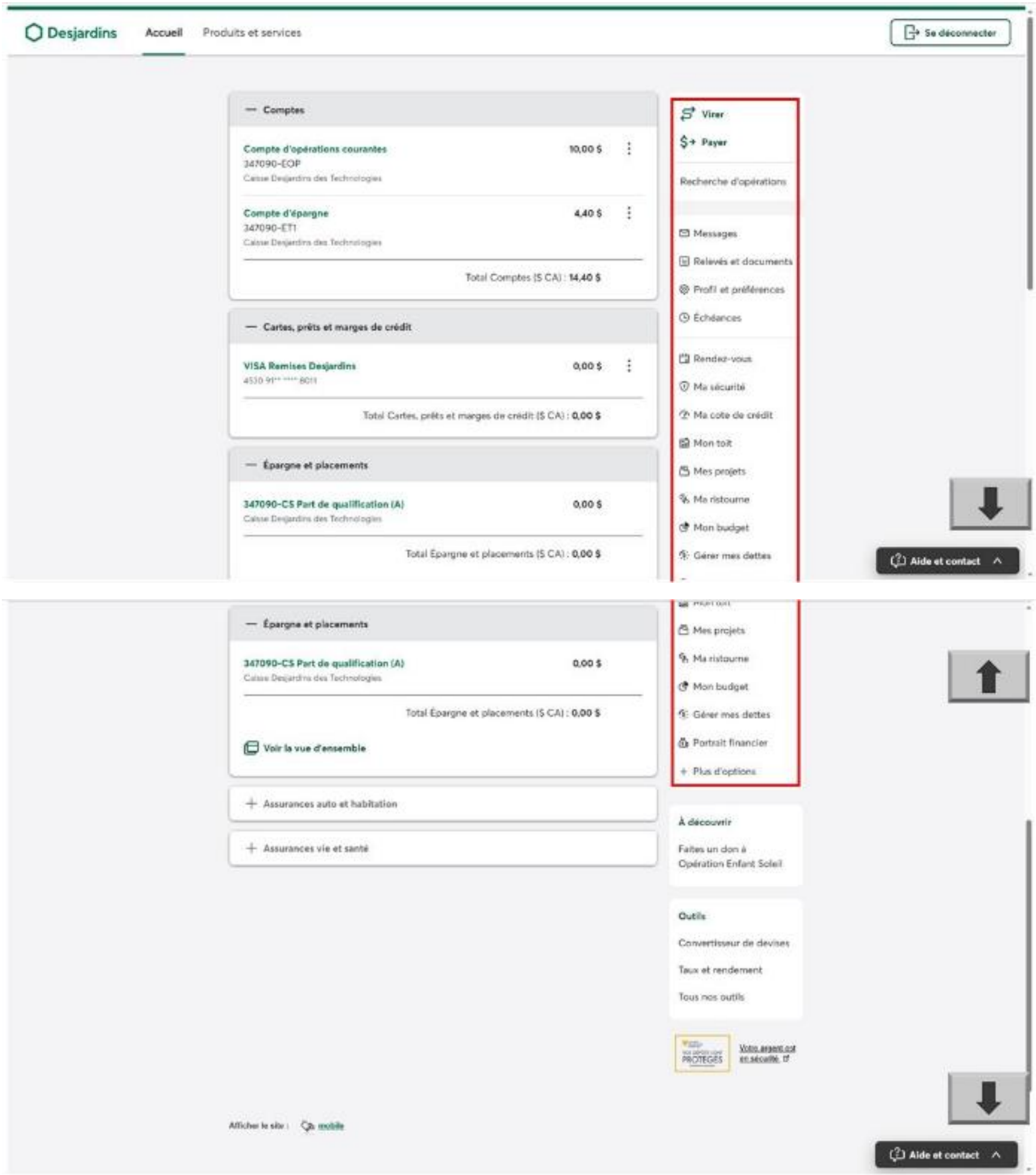


Fig. 2. Higher choice density actual interface. The elements framed in red represent the 17 calls-to-action elements that were reduced to create the lower choice density simplified interface. Participants had to click on the arrows to stimulate scrolling activity.

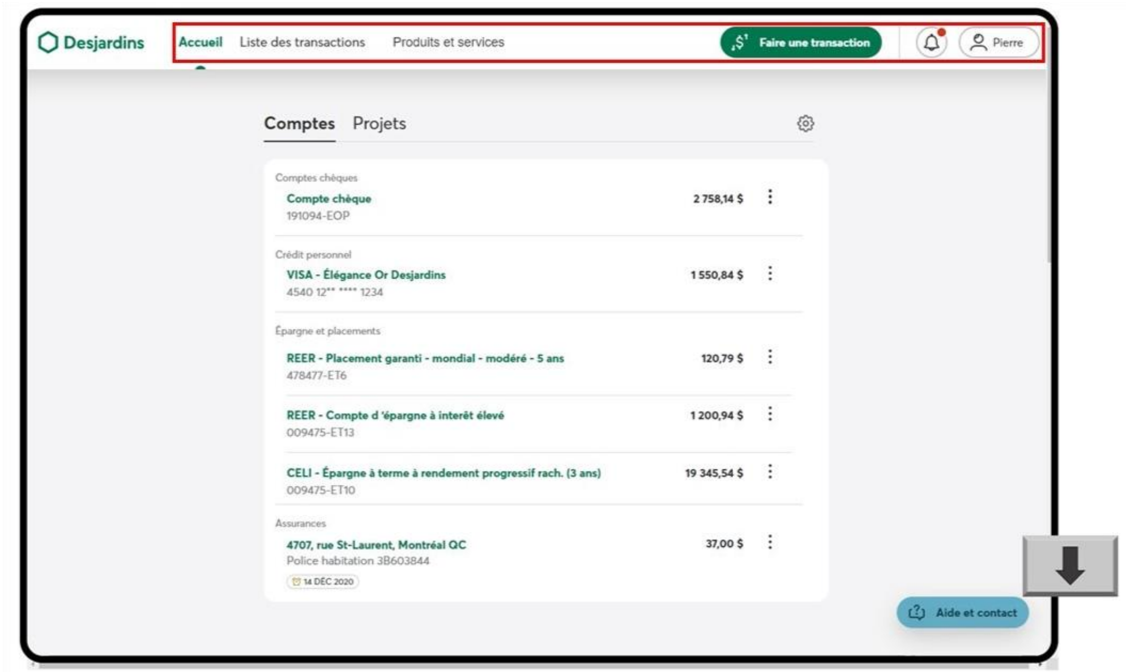
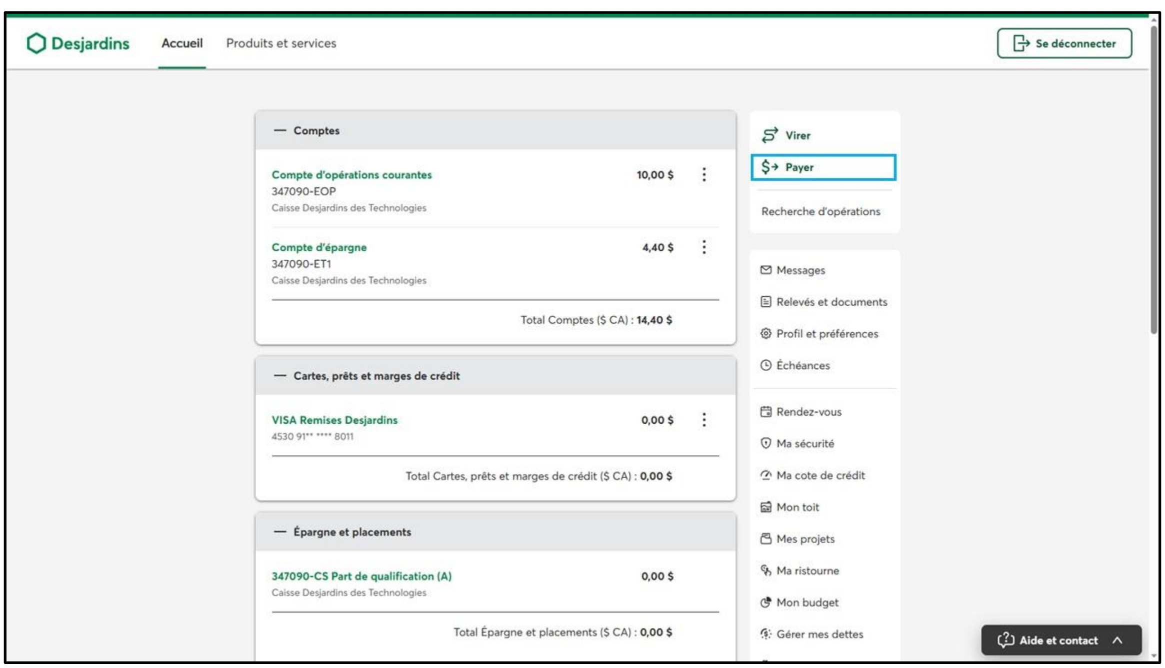
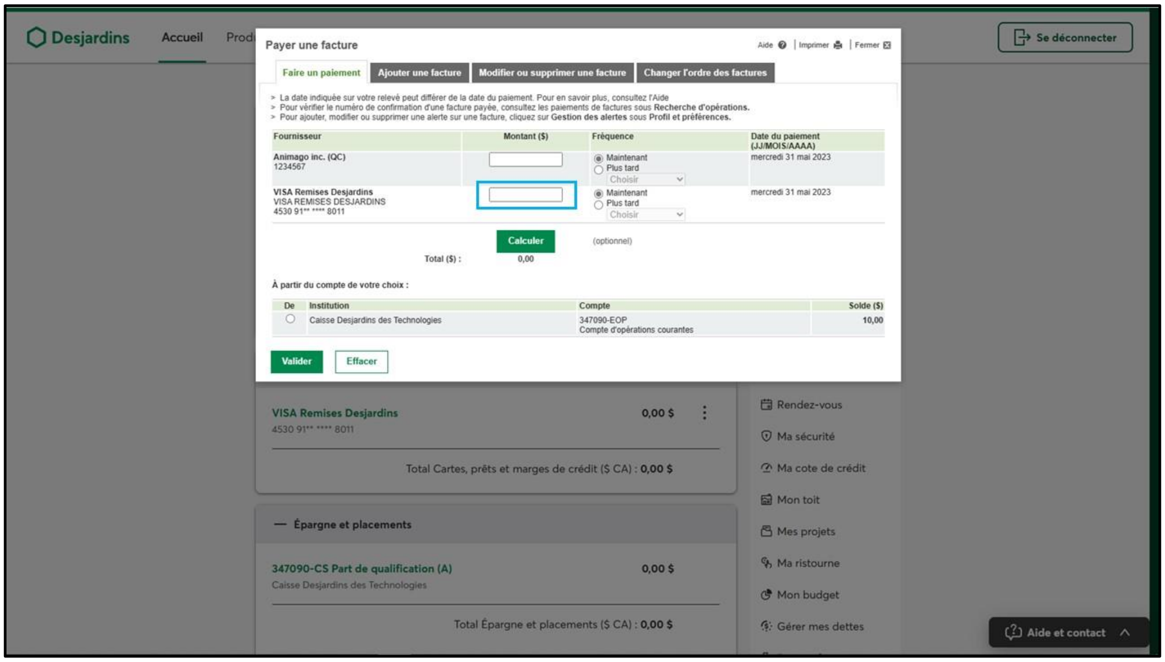
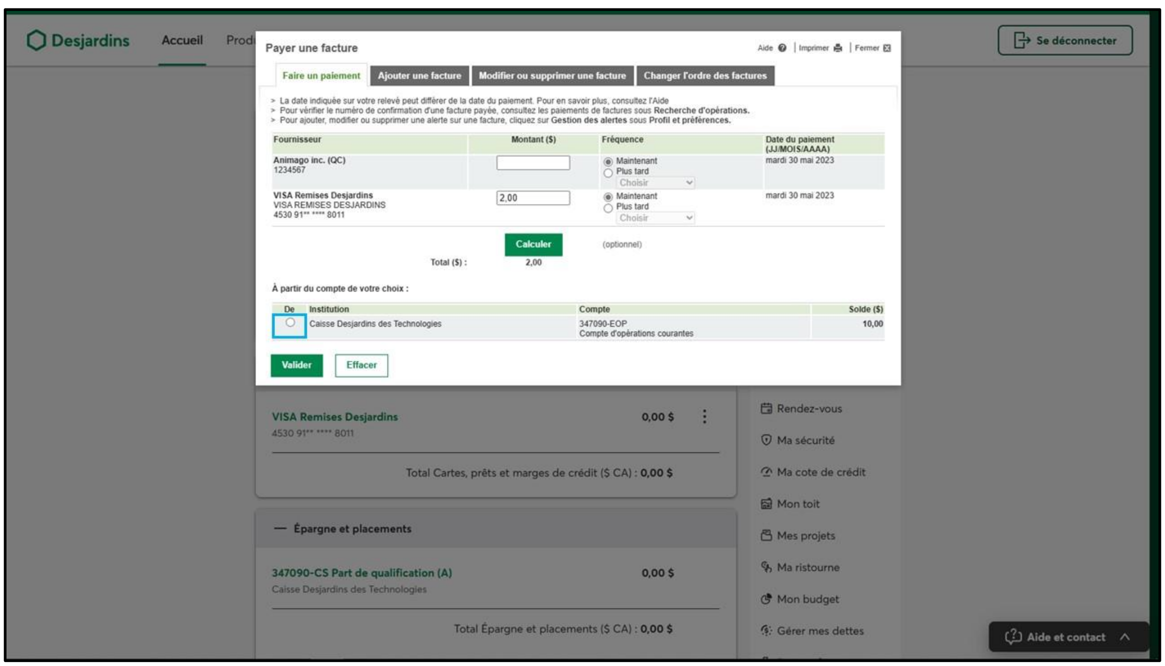


Fig. 3. Lower choice density simplified interface. The elements framed in red represent the 6 call-to-action (CTA) elements created from the 17 CTA in the actual interface (see Figure 2). Participants had to click on the arrows to stimulate the scrolling activity.




Desjardins
Accueil
Se déconnecter
Payer une facture
Aide | Imprimer | Fermer
Faire un paiement
Ajouter une facture
Modifier ou supprimer une facture
Changer l'ordre des factures
La date indiquée sur votre relevé peut différer de la date du paiement. Pour en savoir plus, consultez l'Aide
Pour vérifier le numéro de confirmation d'une facture payée, consultez les paiements de factures sous Recherche d'opérations.
Pour ajouter, modifier ou supprimer une alerte sur une facture, cliquez sur Gestion des alertes sous Profil et préférences.
Fournisseur
Montant ($)
Fréquence
Date du paiement (JJ/MOIS/AAAA)
Animago inc. (QC)
1234567
Maintenant
Plus tard
Choisir
mercredi 31 mai 2023
VISA Remises Desjardins
VISA REMISES DESJARDINS
4530 91** **** 8011
Maintenant
Plus tard
Choisir
mercredi 31 mai 2023
Calculer
(optionnel)
Total ($) :
0,00
À partir du compte de votre choix :
De
Institution
Compte
Solde ($)
Caisse Desjardins des Technologies
347090-EOP
Compte d'opérations courantes
10,00
Valider
Effacer
VISA Remises Desjardins
4530 91** **** 8011
0,00 $
Total Cartes, prêts et marges de crédit ($ CA) : 0,00 $
Épargne et placements
347090-CS Part de qualification (A)
Caisse Desjardins des Technologies
0,00 $
Total Épargne et placements ($ CA) : 0,00 $
Rendez-vous
Ma sécurité
Ma cote de crédit
Mon toit
Mes projets
Ma ristourne
Mon budget
Gérer mes dettes
Aide et contact


Desjardins
Accueil
Se déconnecter
Payer une facture
Aide | Imprimer | Fermer
Faire un paiement
Ajouter une facture
Modifier ou supprimer une facture
Changer l'ordre des factures
La date indiquée sur votre relevé peut différer de la date du paiement. Pour en savoir plus, consultez l'Aide
Pour vérifier le numéro de confirmation d'une facture payée, consultez les paiements de factures sous Recherche d'opérations.
Pour ajouter, modifier ou supprimer une alerte sur une facture, cliquez sur Gestion des alertes sous Profil et préférences.
Fournisseur
Montant ($)
Fréquence
Date du paiement (JJ/MOIS/AAAA)
Animago inc. (QC)
1234567
Maintenant
Plus tard
Choisir
mardi 30 mai 2023
VISA Remises Desjardins
VISA REMISES DESJARDINS
4530 91** **** 8011
2,00
Maintenant
Plus tard
Choisir
mardi 30 mai 2023
Calculer
(optionnel)
Total ($) :
2,00
À partir du compte de votre choix :
De
Institution
Compte
Solde ($)
Caisse Desjardins des Technologies
347090-EOP
Compte d'opérations courantes
10,00
Valider
Effacer
VISA Remises Desjardins
4530 91** **** 8011
0,00 $
Total Cartes, prêts et marges de crédit ($ CA) : 0,00 $
Épargne et placements
347090-CS Part de qualification (A)
Caisse Desjardins des Technologies
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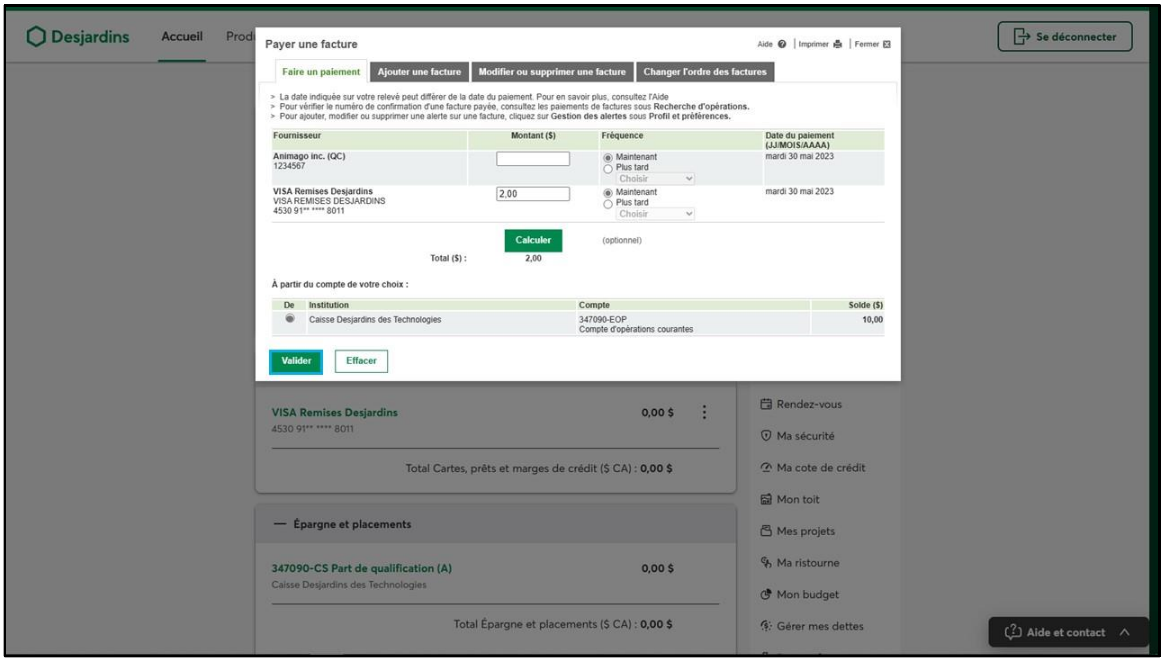
Total Épargne et placements ($ CA) : 0,00 $
Rendez-vous
Ma sécurité
Ma cote de crédit
Mon toit
Mes projets
Ma ristourne
Mon budget
Gérer mes dettes
Aide et contact



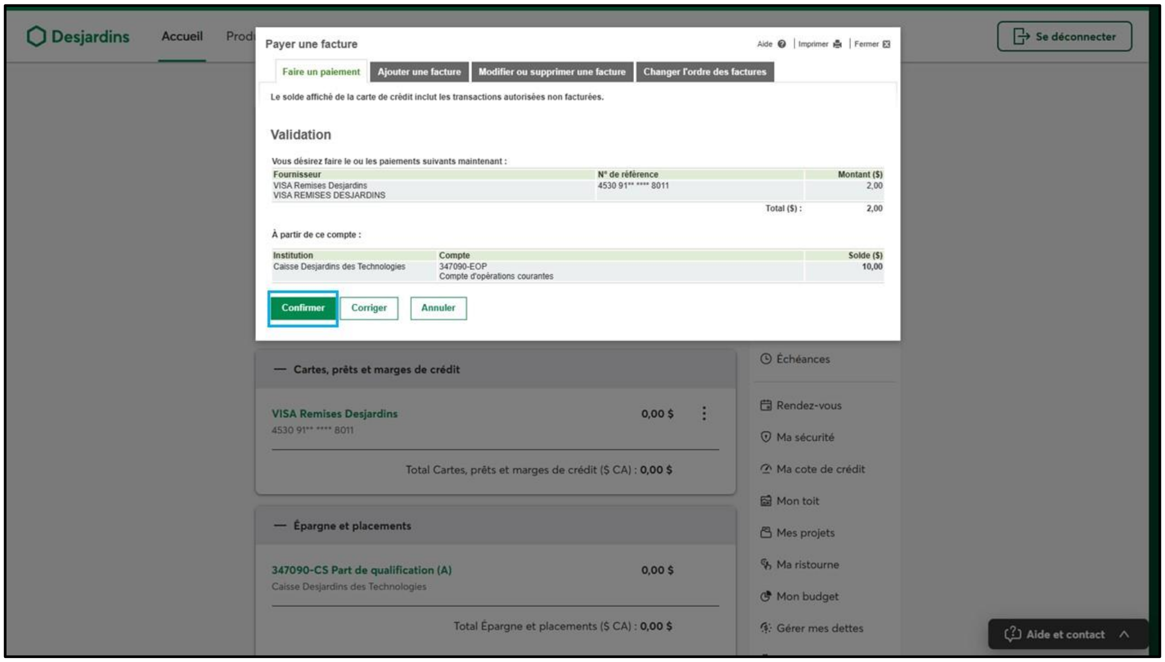
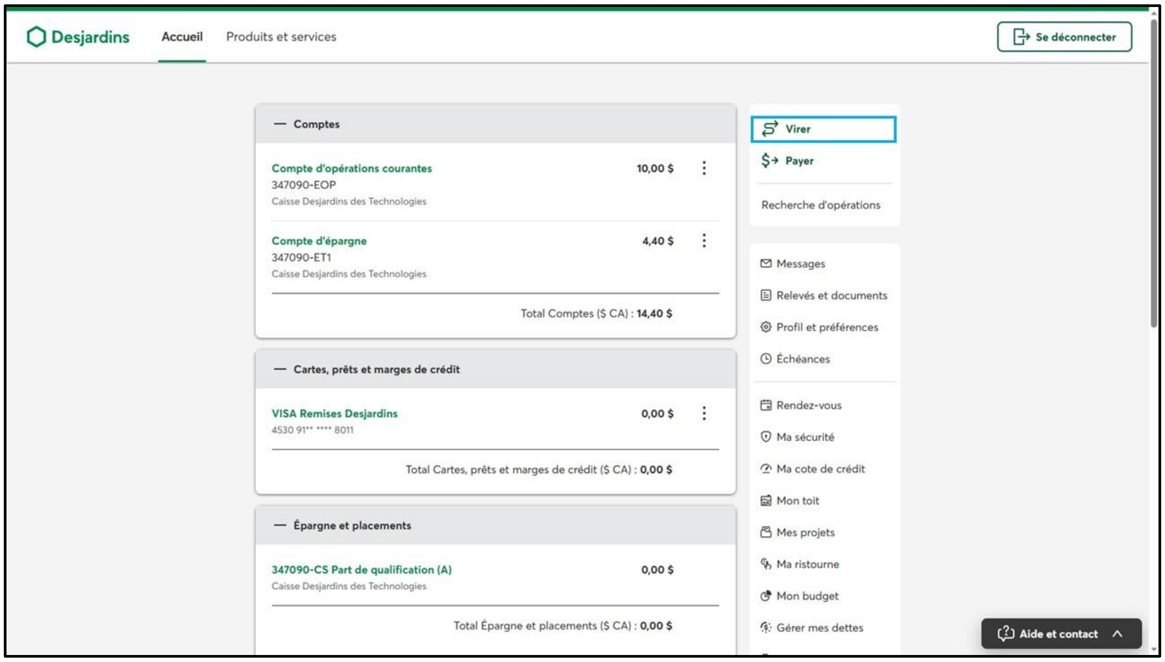
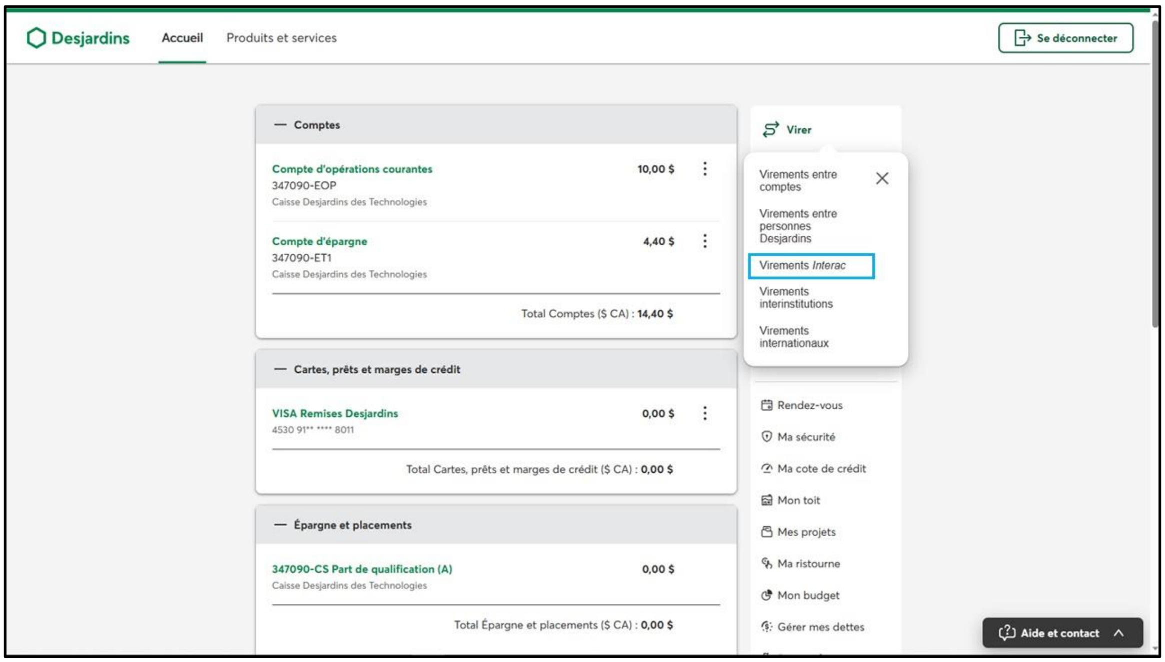


Fig. 4. From top to bottom, pages of the steps to complete Task 1 (actual interface): It's the end of the month and you must pay $2 on your credit card. Participants had to select the buttons framed in blue to move on to the next step of the task.


Desjardins
Accueil
Produits et services
Se déconnecter
Comptes
Compte d'opérations courantes
347090-EOP
Caisse Desjardins des Technologies
10,00 $
Compte d'épargne
347090-ET1
Caisse Desjardins des Technologies
4,40 $
Total Comptes ($ CA) : 14,40 $
Cartes, prêts et marges de crédit
VISA Remises Desjardins
4530 91** **** 8011
0,00 $
Total Cartes, prêts et marges de crédit ($ CA) : 0,00 $
Épargne et placements
347090-CS Part de qualification (A)
Caisse Desjardins des Technologies
0,00 $
Total Épargne et placements ($ CA) : 0,00 $
Virer
Payer
Recherche d'opérations
Messages
Relevés et documents
Profil et préférences
Échéances
Rendez-vous
Ma sécurité
Ma cote de crédit
Mon toit
Mes projets
Ma ristourne
Mon budget
Gérer mes dettes
Aide et contact


Desjardins
Accueil
Produits et services
Se déconnecter
Comptes
Compte d'opérations courantes
347090-EOP
Caisse Desjardins des Technologies
10,00 $
Compte d'épargne
347090-ET1
Caisse Desjardins des Technologies
4,40 $
Total Comptes ($ CA) : 14,40 $
Cartes, prêts et marges de crédit
VISA Remises Desjardins
4530 91** **** 8011
0,00 $
Total Cartes, prêts et marges de crédit ($ CA) : 0,00 $
Épargne et placements
347090-CS Part de qualification (A)
Caisse Desjardins des Technologies
0,00 $
Total Épargne et placements ($ CA) : 0,00 $
Virer
Virements entre comptes
Virements entre personnes Desjardins
Virements Interac
Virements interinstitutions
Virements internationaux
Rendez-vous
Ma sécurité
Ma cote de crédit
Mon toit
Mes projets
Ma ristourne
Mon budget
Gérer mes dettes
Aide et contact

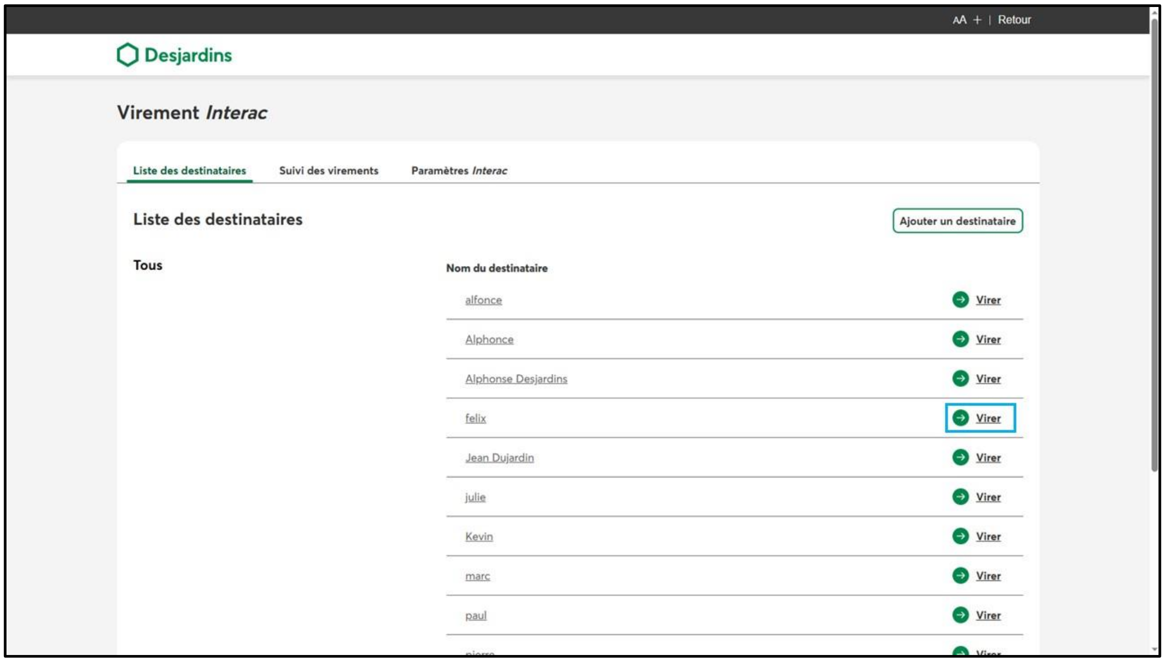


Fig. 5. From top to bottom, pages of the steps to complete Task 2 (actual interface): Your friend Felix lent you $2. Make an Interac transfer to pay him back. Participants had to select the buttons framed in blue to move on to the next step of the task.

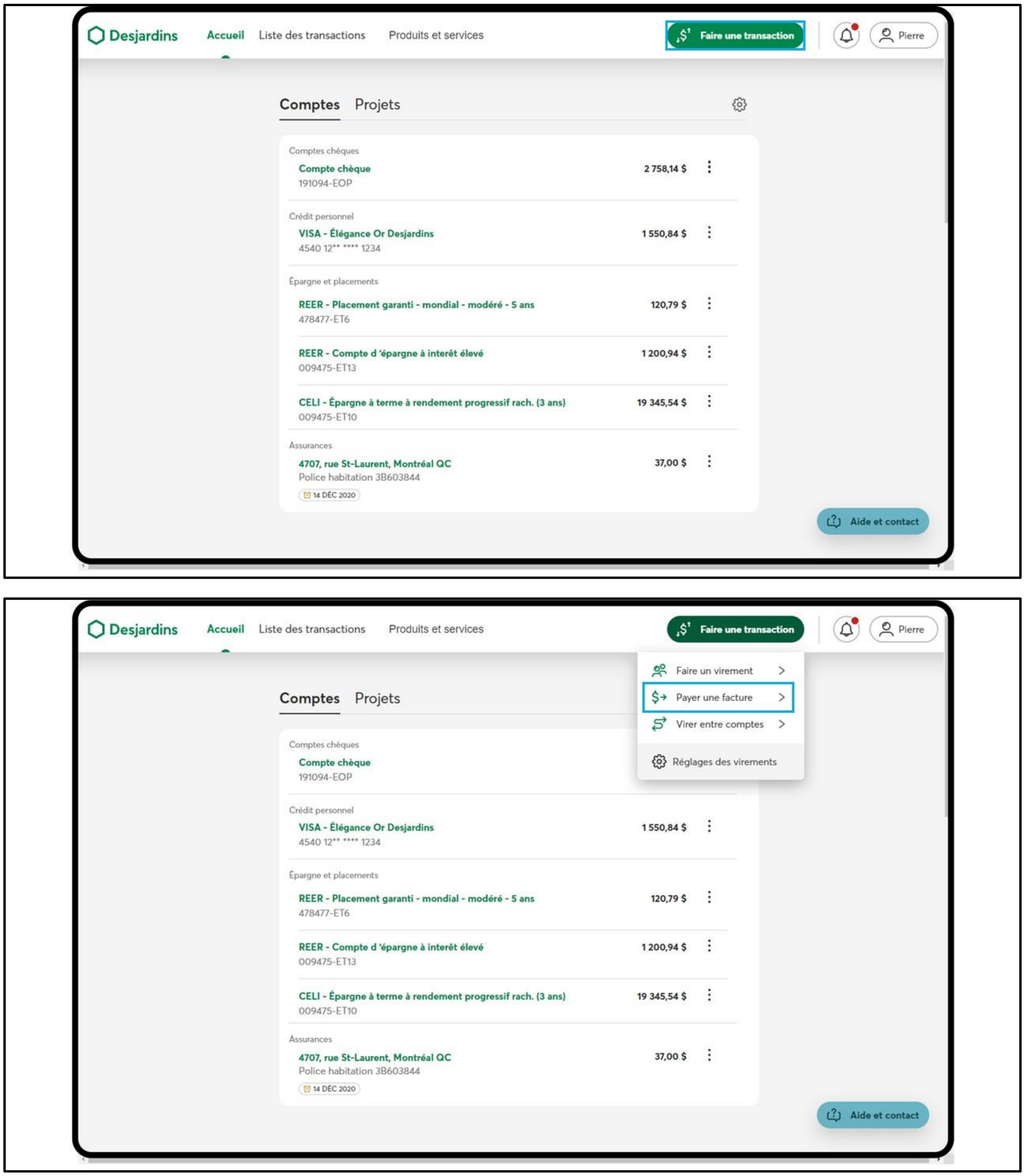
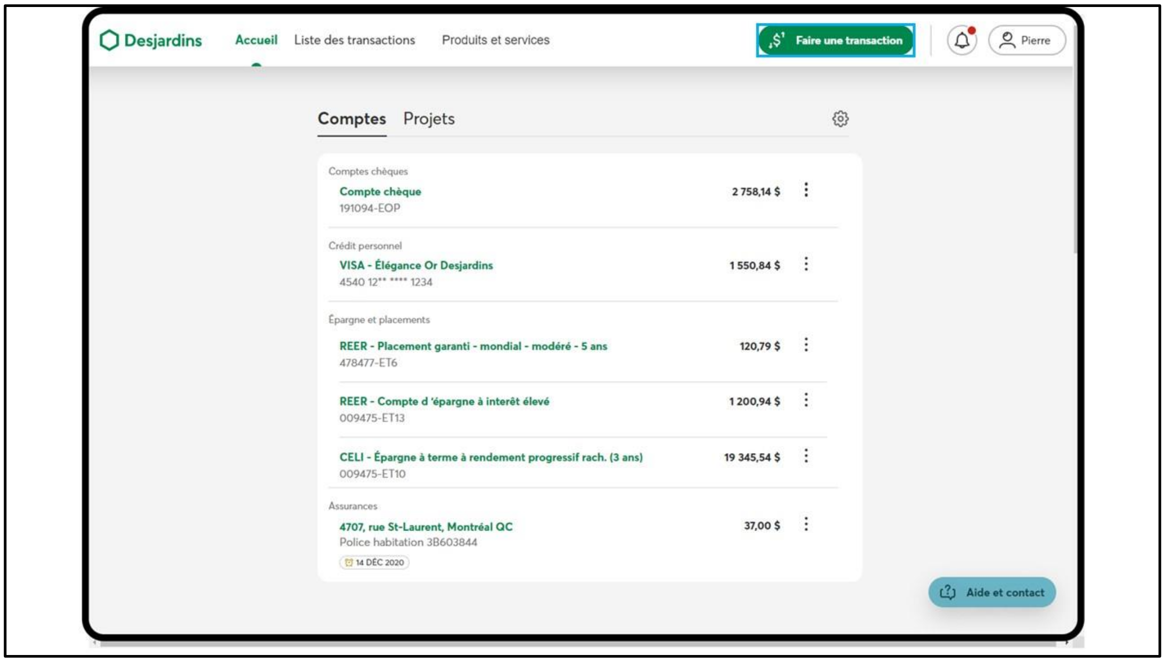


Fig. 6. From top to bottom, pages of the steps to complete Task 3 (simplified interface): It's the end of the month and you need to pay your $2 Netflix bill. Participants had to select the buttons framed in blue to move on to the next step of the task.



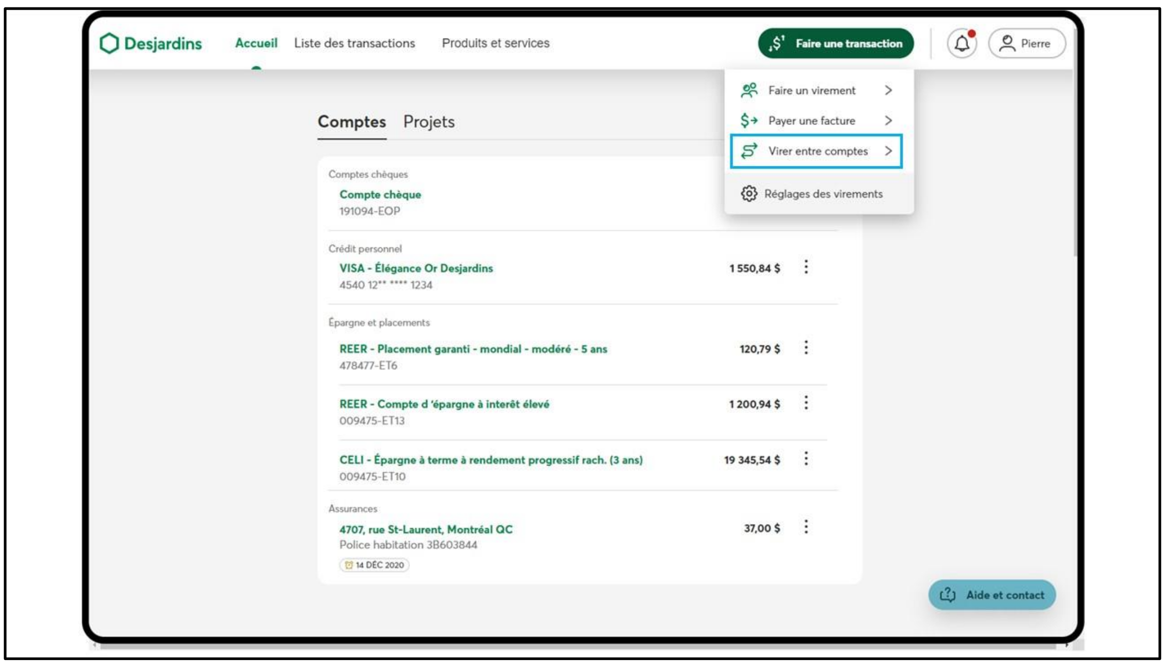
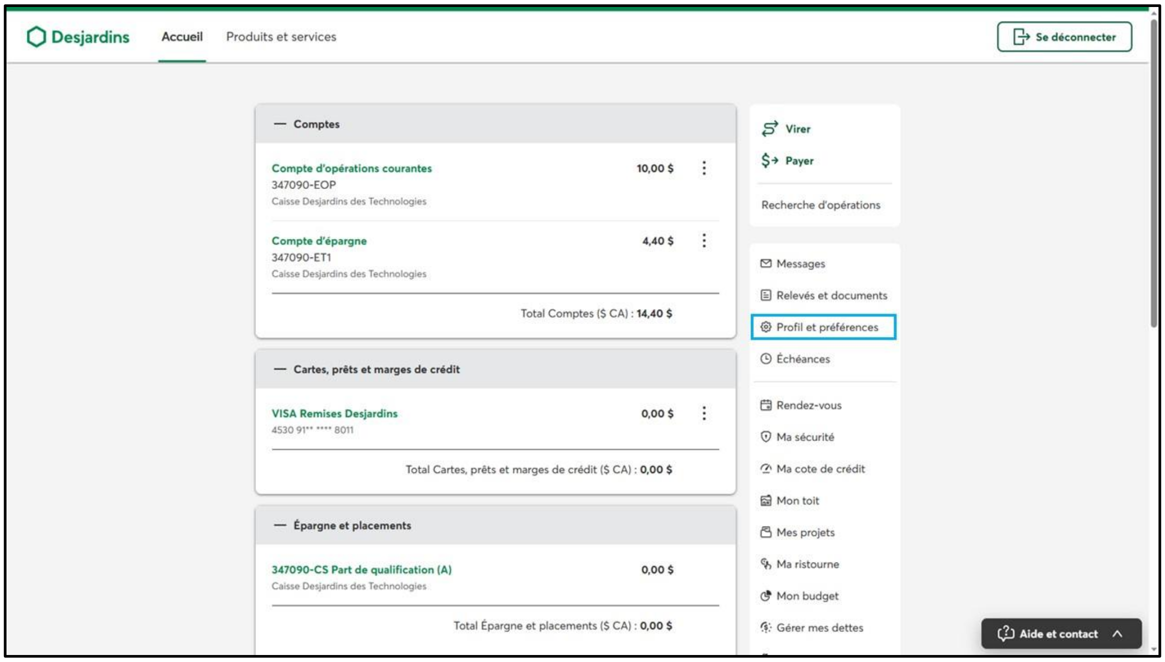
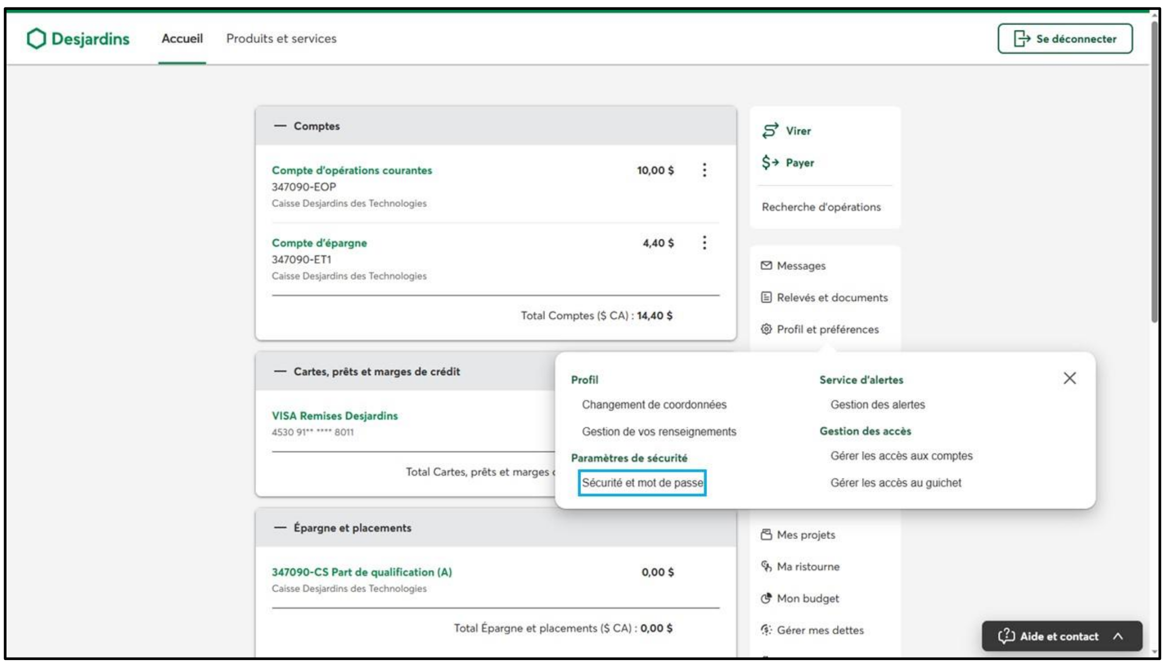


Fig. 7. From top to bottom, pages of the steps to complete Task 4 (simplified interface): It's the end of the month and you must pay $2 on your credit card. Participants had to select the buttons framed in blue to move on to the next step of the task.


Desjardins
Accueil
Produits et services
Se déconnecter
Comptes
Compte d'opérations courantes
10,00 $
347090-EOP
Caisse Desjardins des Technologies
Compte d'épargne
4,40 $
347090-ET1
Caisse Desjardins des Technologies
Total Comptes ($ CA) : 14,40 $
Cartes, prêts et marges de crédit
VISA Remises Desjardins
0,00 $
4530 91** **** 8011
Total Cartes, prêts et marges de crédit ($ CA) : 0,00 $
Épargne et placements
347090-CS Part de qualification (A)
0,00 $
Caisse Desjardins des Technologies
Total Épargne et placements ($ CA) : 0,00 $
Virer
Payer
Recherche d'opérations
Messages
Relevés et documents
Profil et préférences
Échéances
Rendez-vous
Ma sécurité
Ma cote de crédit
Mon toit
Mes projets
Ma ristourne
Mon budget
Gérer mes dettes
Aide et contact


Desjardins
Accueil
Produits et services
Se déconnecter
Comptes
Compte d'opérations courantes
10,00 $
347090-EOP
Caisse Desjardins des Technologies
Compte d'épargne
4,40 $
347090-ET1
Caisse Desjardins des Technologies
Total Comptes ($ CA) : 14,40 $
Cartes, prêts et marges de crédit
VISA Remises Desjardins
4530 91** **** 8011
Épargne et placements
347090-CS Part de qualification (A)
0,00 $
Caisse Desjardins des Technologies
Total Épargne et placements ($ CA) : 0,00 $
Virer
Payer
Recherche d'opérations
Messages
Relevés et documents
Profil et préférences
Profil
Changement de coordonnées
Gestion de vos renseignements
Paramètres de sécurité
Sécurité et mot de passe
Service d'alertes
Gestion des alertes
Gestion des accès
Gérer les accès aux comptes
Gérer les accès au guichet
Mes projets
Ma ristourne
Mon budget
Gérer mes dettes
Aide et contact

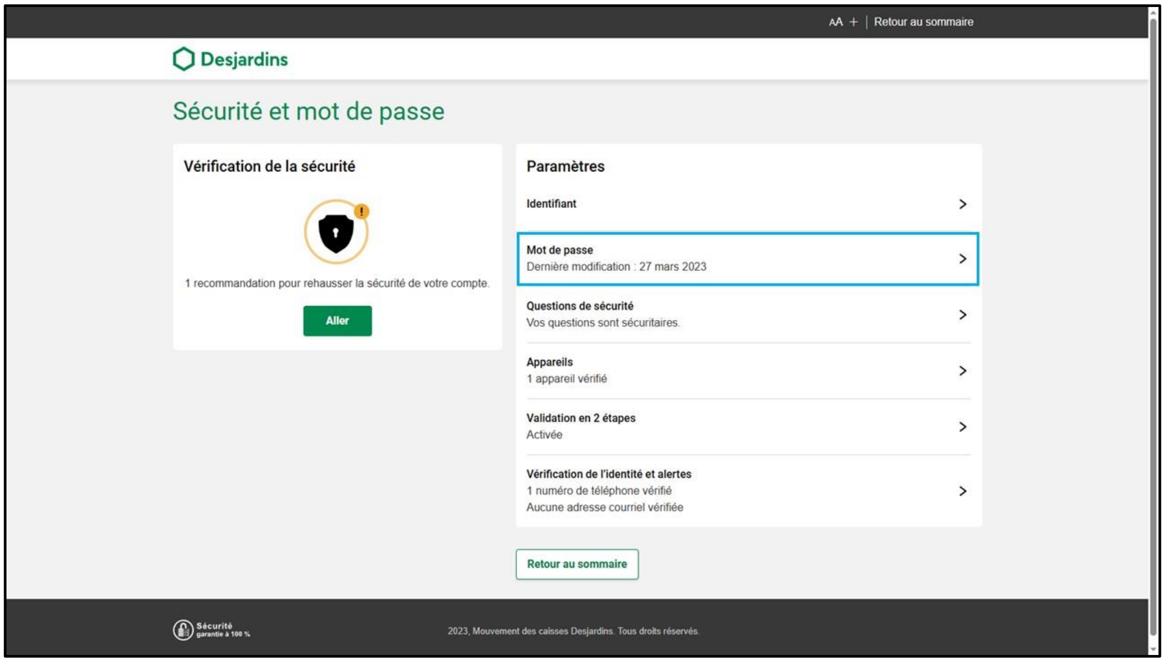


Fig. 8. From top to bottom, pages of the steps to complete Task 5 (actual interface): You want to change the password of your account. There were two possible paths in this task. In this path, participants had to select the buttons framed in blue to move on to the next step of the task.

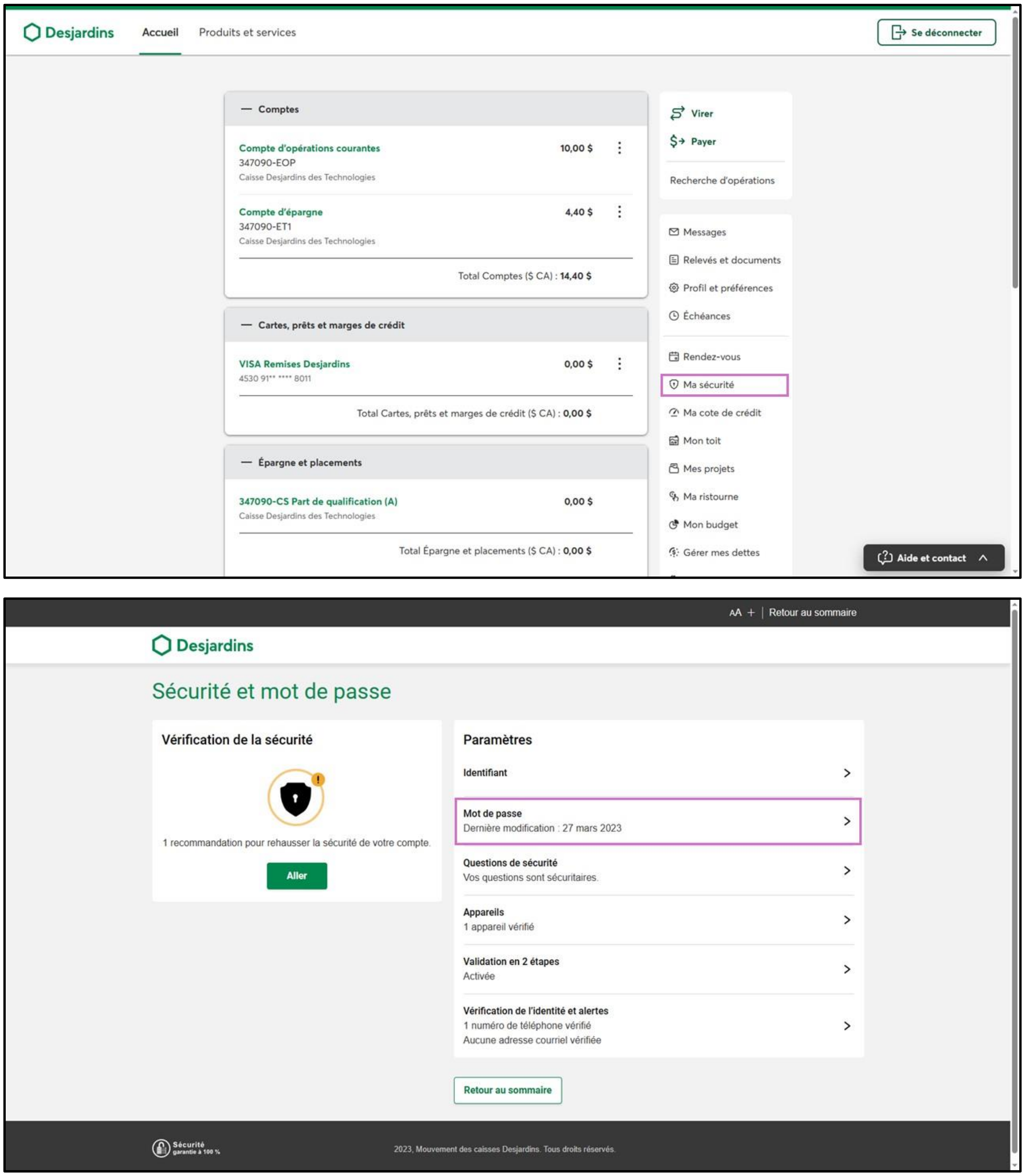
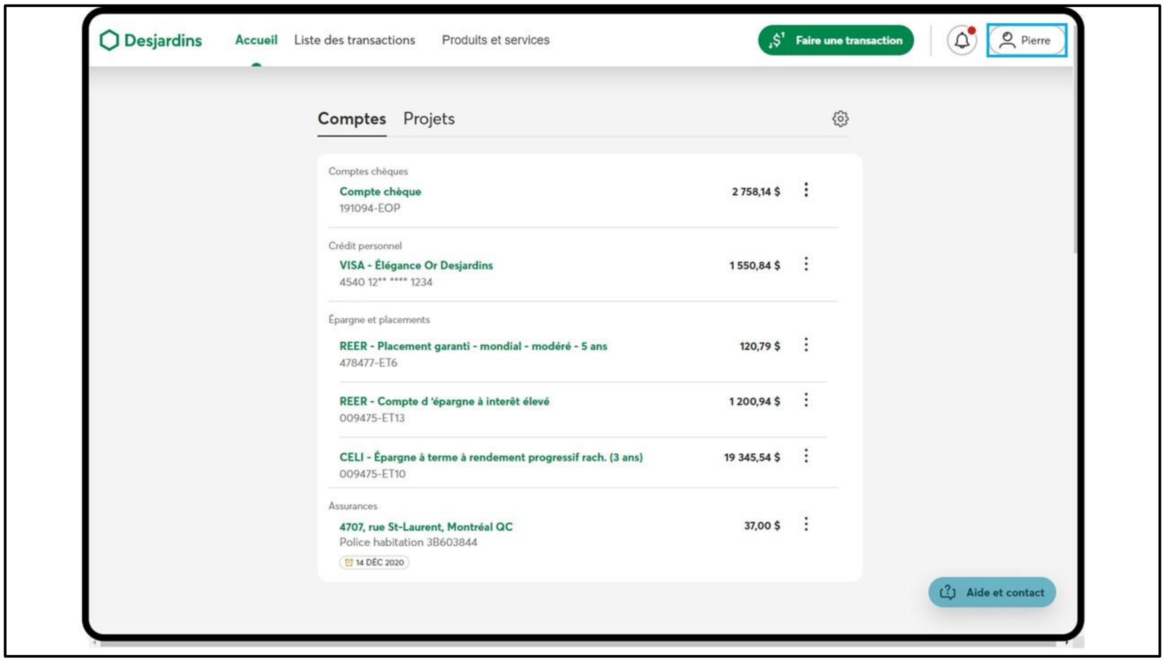
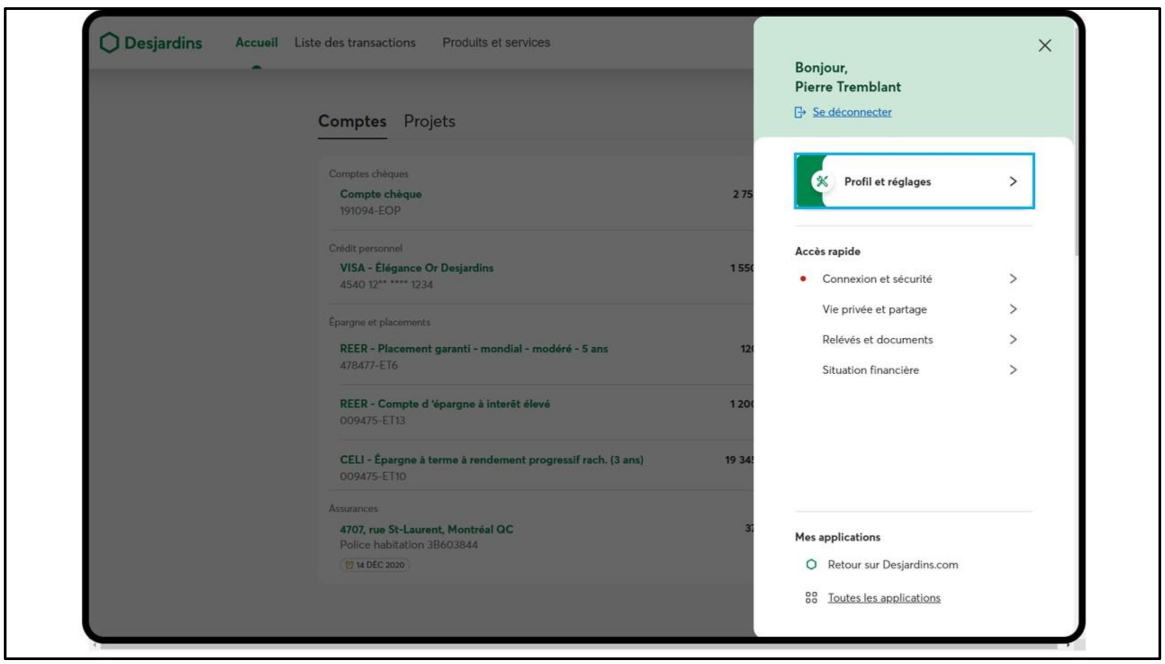


Fig. 9. From top to bottom, pages of the steps to complete Task 5 (actual interface): You want to change the password of your account. There were two possible paths in this task. In this path, participants had to select the buttons framed in purple to move on to the next step of the task.


Desjardins
Accueil
Liste des transactions
Produits et services
Faire une transaction
Pierre
Comptes
Projets
Comptes chèques
Compte chèque
191094-EOP
2 758,14 $
Crédit personnel
VISA - Élégance Or Desjardins
4540 12** **** 1234
1 550,84 $
Épargne et placements
REER - Placement garanti - mondial - modéré - 5 ans
478477-ET6
120,79 $
REER - Compte d 'épargne à interêt élevé
009475-ET13
1 200,94 $
CELI - Épargne à terme à rendement progressif rach. (3 ans)
009475-ET10
19 345,54 $
Assurances
4707, rue St-Laurent, Montréal QC
Police habitation 3B603844
14 DÉC 2020
37,00 $
Aide et contact


Desjardins
Accueil
Liste des transactions
Produits et services
Comptes
Projets
Comptes chèques
Compte chèque
191094-EOP
Crédit personnel
VISA - Élégance Or Desjardins
4540 12** **** 1234
Épargne et placements
REER - Placement garanti - mondial - modéré - 5 ans
478477-ET6
REER - Compte d 'épargne à interêt élevé
009475-ET13
CELI - Épargne à terme à rendement progressif rach. (3 ans)
009475-ET10
Assurances
4707, rue St-Laurent, Montréal QC
Police habitation 3B603844
14 DÉC 2020
Bonjour,
Pierre Tremblant
Se déconnecter
Profil et réglages
Accès rapide
Connexion et sécurité
Vie privée et partage
Relevés et documents
Situation financière
Mes applications
Retour sur Desjardins.com
Toutes les applications

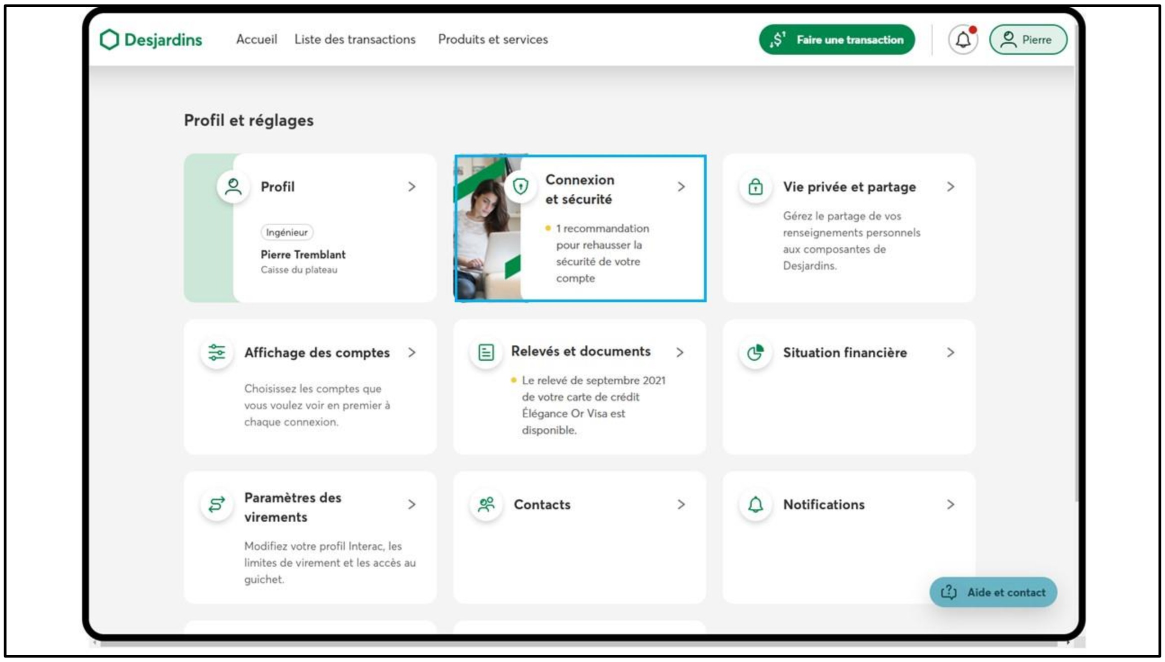


Fig. 10. From top to bottom, pages of the steps to complete Task 6 (simplified interface): You've received your paycheque in your chequing account and want to transfer $2 of that money to your savings account. There were two possible paths in this task. In this path, participants had to select the buttons framed in blue to move on to the next step of the task.

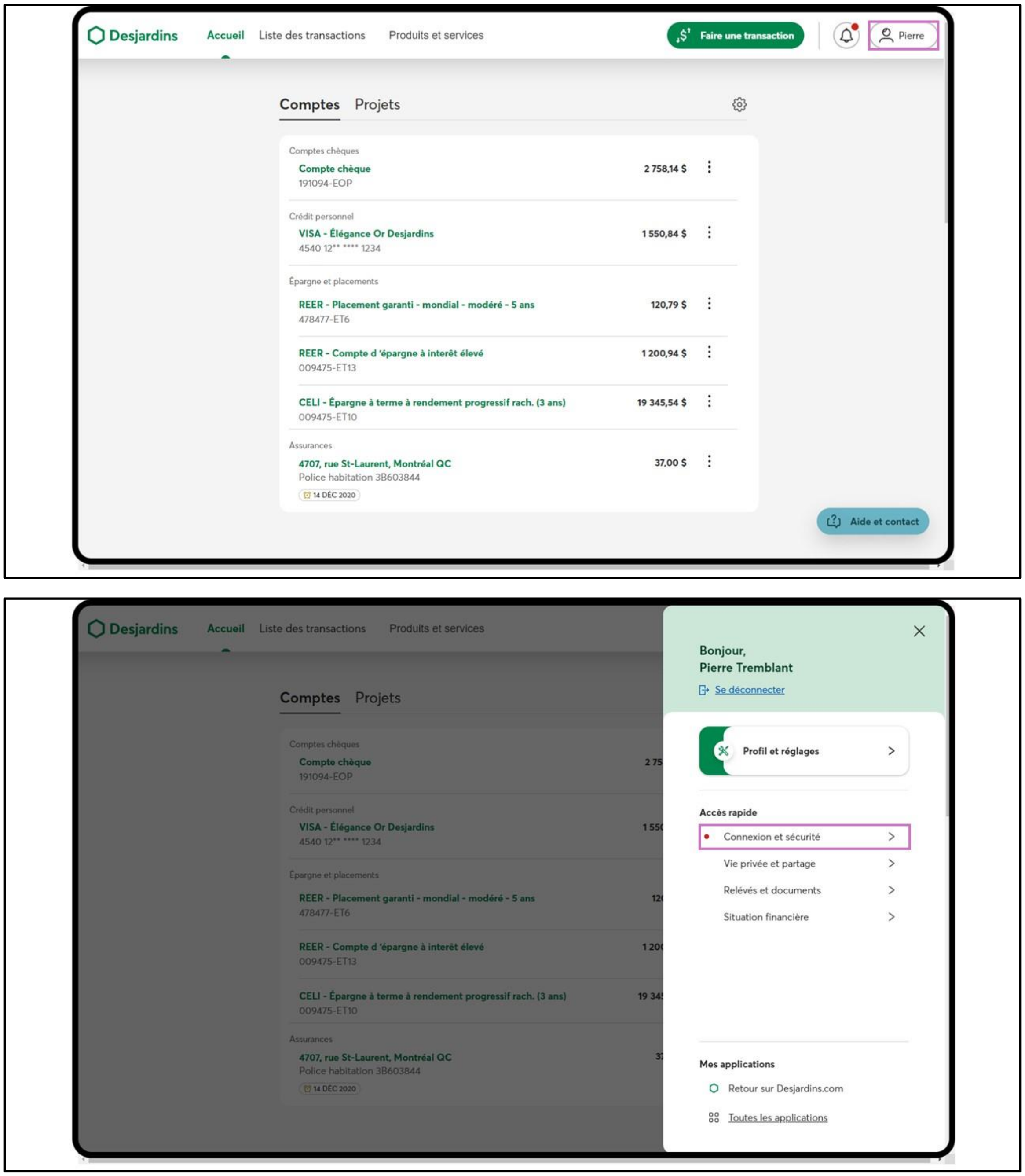


Fig. 11. From top to bottom, pages of the steps to complete Task 6 (simplified interface): You've received your paycheque in your chequing account and want to transfer $2 of that money to your savings account. In this path, participants had to select the buttons framed in purple to move on to the next step of the task.

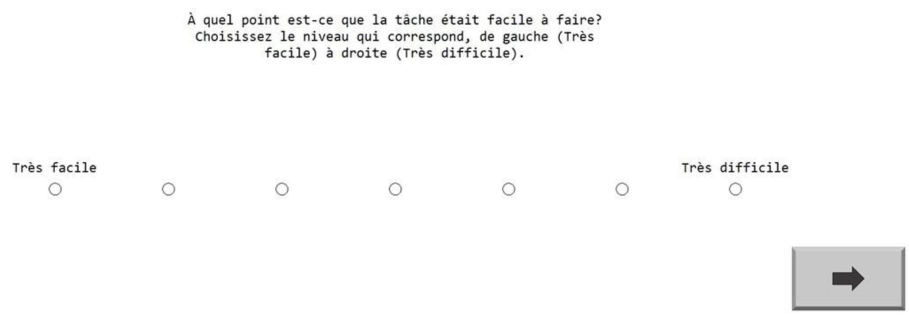


Fig. 12. Adapted single-item self-reported effort scale. The text means "How easy was the task? Select the corresponding level, from left (Very Easy) to right (Very Difficult)". The text on the far left of the scale means "Very easy" and the text on the far right means "Very difficult". This question was presented visually to the participant and read aloud.

Triggers representing the start and end of each trial were sent from E-Prime 3 to both the Observer XT (Noldus, Wageningen, Netherlands) and Brainvision recorder (Brain ProductsGmbH, Munich, Germany) softwares. To synchronize the data, Observer XT also sent a trigger every 30 seconds to both Brainvision recorder and Tobii Pro Lab (Tobii AB, Danderyd, Sweden) softwares. The Brainvision recorder software was used to record raw and visualize EEG data at a 500 Hz sampling rate. A 32-electrode montage was used for this study (actiCAP, BrainProducts, GmbH, Munich, Germany) and was installed according to the 32 channels Standard-2 Cap layout for the actiCAP. Qualtrics (Qualtrics, Provo, Utah, USA) was used to build the questionnaires which were then presented to the participants on an Ipad. The MediaRecorder software (Noldus Information Technology BV, Wageningen, Netherlands) was used to record the Webcam video of the participants' computer.

3.4.4 Procedure

Participants were contacted 24 hours before their session to confirm their presence and answer their questions. For the experimental group, an audio recording of the consent form was sent to them through the non-for-profit literacy organization they attended. It was indicated to participants that they needed to listen to the recording the day before their experimental session. They were also offered a step-by-step plan on how to arrive at the experiment's location. If they wanted to, they could also ask to have a research assistant come to wait for them in the nearby subway station on the day of the experiment.

At the beginning of the session, if a participant from the experimental group had not listened to the recording of the consent form, research assistants played it for them. They then provided oral consent, which was recorded by the research assistants. This method of consent was chosen to provide comfort and ensure comprehension for the functional illiterate participants. For the control group, the audio recording of the consent form was not sent. Instead, they read the consent form on the day of the experiment and provided written consent. All participants were informed that they could ask questions at any time during the procedure. Socio-demographic questions and their self-perceived level of financial literacy were asked after consent was provided.

The participant's head circumference was then measured to select the appropriate electroencephalography (EEG) cap. Conductive gel was applied to all 32 channels and impedance was verified. Afterwards, the Tobii Pro Lab (Tobii AB, Danderyd, Sweden) eye tracker was calibrated with a 9-point calibration. The screen recording was then started on Tobii Pro Lab and then the E-Prime 3 (Psychology Software Tools, Pittsburgh, PA, United States) experiment was launched through Observer XT (Noldus, Wageningen, Netherlands). Before the study was explained, participants were instructed to remain still and look at a fixation cross for a period of 90 seconds which would be used as a baseline for EEG analysis.

The study's general instructions were given orally to participants. Participants were also made aware that they would be using a prototype of the interfaces which meant that some buttons were deactivated and that scrolling the page was done through arrow buttons.

For each trial, the task that had to be done was presented on the participant's screen but orally given to ensure comprehension. When the participant was ready, the research assistant started the task. At the end of the trial, the self-reported effort scale was presented on the participant's screen and given orally. Research assistants then read that question out loud the first time it appeared for all participants, including the control group, and make a judgment call depending on how the participant reacted for whether it was necessary to do so with all the other trials. After the experiment was over, data recording was stopped. The questionnaire assessing the level of financial literacy was then presented orally to the participants.

The research assistant then removed the EEG cap, and the participant was thanked and informed that they could wash their hair on location if they wanted to. For their participation, the participants in the control group were compensated by a CAD 200 e-transfer through the external recruitment firm. For the experimental group, participants were given their compensation in the form of a CAD 250 prepaid credit card. The research assistant then offered the experimental group participants to accompany them to the nearby subway station.

3.4.5 Measures

For the measure of performance, the completion time and the success rate of each task were recorded (Hussain et al., 2018; Inan Nur et al., 2021). Additionally, for each task, the moderator took note of the number of times a participant would ask or need help to continue as well as the number of times the participant needed to be reminded of the task's objective.

EEG data were continuously recorded during the experiment to study the cognitive processes involved during the tasks including effort (Antonenko et al, 2010; Cohen, 2017; Kumar and Kumar, 2016). The perceived effort was measured after each task with a single-item 7-point Likert scale (1 = Very easy to 7 = Very difficult). In human-computer interaction (HCI), effort or cognitive load is often measured by single-item scales such as the Customer Effort Score due to their practical advantages in speed, despite multi-item scales such as the NASA Task Load Index being more representative (Cuvillier et al., 2021;

Dixon et al., 2010, Sweller et al., 2011). This is particularly relevant to the present study because questions had to be administered both visually and orally to ensure comprehension for functional illiterate participants. As mentioned, the scale was adapted following the recommendations by literacy experts from the non-for-profit literacy organizations. Therefore, only the labels for points 1 and 7 of the scale (very easy and very difficult respectively) were visible to avoid overloading the functional illiterate participants with visual information (Viswanathan et al., 2005).

Table 2.

Operationalization of the variables

Variables	Measure	Tool	References
Literacy	Literacy Level	Recruitment from a literacy foundation or not	
Choice Density	Number of Calls-to-Action (CTAs)	Actual Version of Interface vs Simplified Version of Interface	
Performance	Response Time	E-Prime 3	Inan Nur et al. (2021)
	Success Rate	Observation	
Effort	Self-Perceived Effort	Adapted single item 7-points Likert scale	Cuvillier et al. (2021)

Theta (5-7 Hz) Alpha (8-12 Hz) Beta (15-29 Hz)	Electroencephalography (EEG)	Antonenko et al (2010)

3.4.6 Analysis

The analyses were conducted on SAS and the threshold for significance was set at $p < 0.05$. If effects or interactions were significant, pairwise comparisons were performed and corrected with Holm.

Behavioral and self-perceived effort analysis

The independent variables for these analyses were group (2) and interface type (2).

Completion Time

A linear regression with random intercept model was used for the completion time. To improve the performance of the model, because the original distribution was not normal, the analysis was done by coding a new value using a logarithmic transformation: log (completion time). This transformed variable is hereafter referred to as “Completion time”.

Success

A cumulative logistic regression with random intercept model was used for success. Because the original binary coding of this variable was considered too strict by the research team (1 = Success; 0 = Fail), it was changed to include a partial success: 2 = the participant completes the task without asking or needing help (success); 1 = the participant completes the task by asking or needing help at one or multiple steps except the last step of the task (partial success); 0 = the participant does not complete the last step of the task on their own (fail). Additionally, the regression analyses for the interaction model (group by interface) did not converge and therefore yielded no results.

Self-Perceived Effort

A logistic regression with random intercept model was used for the self-perceived effort measured with an adapted single-item scale. To use this analysis, since data was collected on a 7-points scale, the data was recoded as a binary value of high effort and low effort (1 = effort > 3; 0 = effort ≤ 3). This transformed variable is hereafter referred to as "Self-Perceived Effort".

<u>EEG</u>

For each frequency band separately, theta (5-7 Hz), alpha (8-12 Hz), and beta (15-29 Hz), a repeated measures (RM) ANOVA was used to analyze the effect of the independent variables: Group (2), interface type (2) and channel (32 channels).

Pre-processing

Raw EEG data was recorded at a sampling rate of 500 Hz and processed with the open-source application Brainstorm which was run via MATLAB (MathWorks, Natick, MA, USA). Dead or noisy channels were removed manually when visualizing raw data. An independent component analysis (ICA) was then run to separate and remove independent signal sources related to artifacts that may affect the data (i.e. blinks and heartbeats). After the EEG data was cleaned, a band-pass filter of 1-40 Hz was applied.
EEG data related to the present study's events, the 90 s baseline and the six tasks, were epoched at –100 ms to 400 ms relative to each marker that was set at 3 s intervals during the event. The baseline had 30 epochs of 3 s. For each task, the data was marked relative to the fastest completion time in both groups separately (see Table 3). For example, in the control group, the fastest completion time for Task 1 was 13.01 s, so the data was marked in 3 s intervals until reaching 9 s, resulting in 4 epochs. The epochs were then visually inspected and removed if the EEG signal contained noise or artifacts (amplitude exceeded +/- 150 µV).

Table 3.

Number of epochs for each task for the experimental and control group

Task	Group	Fastest Completion Time (seconds)	Number of Epochs
Task 1	Experimental	37.05	12
	Control	13.01	4
Task 2	Experimental	45.94	15
	Control	6.02	2
Task 3	Experimental	10.38	3
	Control	4.20	1
Task 4	Experimental	42.20	14
	Control	3.10	1
Task 5	Experimental	61.07	20
	Control	7.55	2

Task 6	Experimental	109.04	36
	Control	7.10	2

Afterward, using a Hilbert transform, a source-level time-frequency decomposition could be run on the epochs of all participants for each frequency band of interest (alpha, beta, and theta). For each event, the time-frequency envelopes were averaged across epochs for all bands. To get the event-related perturbation (ERS/ERD), the average signal of each task event was then normalized relative to the baseline signal using the formula $x_{std} = (x - \mu)/\mu*100$ (X = time-frequency envelope's amplitude to normalize, μ = time average over the baseline). Finally, each standardized signal for the six task events was averaged across a 3 s period for statistical analysis.

3.5 Results

Table 4.

Descriptive statistics of completion time, success rate, self-perceived effort, and EEG theta, alpha, and beta by group and interface type

Group	Interface Type	Completion Time (seconds)	Success Rate	Self-Perceived Effort	Theta (%)	Alpha (%)	Beta (%)
Low Literacy	Lower Choice Density	11.00 ± 1.01 (N = 34)	1.03 ± 0.90 (N = 39)	0.71 ± 0.46 (N = 42)	-5.15 ± 47.06 (N = 972)	-20.70 ± 35.82 (N = 970)	16.49 ± 59.59 (N = 927)
	Higher Choice Density	10.83 ± 1.20 (N = 36)	1.08 ± 0.74 (N = 39)	0.81 ± 0.40 (N = 42)	-6.62 ± 48.17 (N = 977)	-19.88 ± 35.21 (N = 975)	18.36 ± 58.84 (N = 934)
Literate	Lower Choice Density	8.92 ± 0.69 (N = 32)	1.88 ± 0.48 (N = 33)	0.03 ± 0.17 (N = 33)	9.62 ± 51.00 (N = 802)	-33.45 ± 39.70 (N = 815)	-2.74 ± 41.92 (N = 812)
	Higher Choice Density	8.79 ± 0.93 (N = 33)	2.00 ± 0.00 (N = 33)	0.06 ± 0.24 (N = 33)	11.77 ± 47.92 (N = 808)	-31.47 ± 42.94 (N = 816)	-4.29 ± 44.54 (N = 815)

3.5.1 Performance

H1: Effect of literacy on performance

Completion time was significantly different between groups ($p < 0.0001$), with the low literacy group taking longer to complete a task (11.21 ± 1.14 s) than the literate group (9.30 ± 1.12 s). Additionally, the success rate was significantly different between groups ($p < 0.0001$), with the low literacy group having a lower success rate during the tasks (0.98 ± 0.80) than the literate group (1.89 ± 0.47). Therefore, hypothesis H1 is supported.

H3: Effect of choice density on performance

There was no significant difference in the task completion time ($p = 0.299$) between the lower choice density interface (9.99 ± 1.36 s) and the higher choice density interface (9.85 ± 1.49 s). Additionally, there was no significant difference in the success rate ($p = 0.539$) between the lower choice density interface (1.42 ± 0.85) and the higher choice density interface (1.50 ± 0.71). Therefore, hypothesis H3 is not supported.

H5: Effect of literacy and choice density interaction on performance

There was also no significant group by interface type interaction effect detected for completion time ($F_{(1, 110)} = 0.03$, $p = 0.868$). Additionally, for the success rate, the regression analyses for the interaction model (group by interface) did not converge and thus yielded no results. Therefore, hypothesis H5 is not supported.

3.5.2 Effort

H2: Effect of literacy on effort

The self-perceived effort was significantly different between groups ($p < 0.0001$), with the low literacy group tending to find tasks more difficult (0.76 ± 0.43) than the literate group (0.11 ± 0.32).

RM ANOVA of theta (5-7 Hz) showed no significant effect of group ($F_{(1, 3413)} = 0.68$, $p = 0.410$) but there was a significant effect of channel ($F_{(31, 3413)} = 15.57$, $p < 0.0001$). There was also a significant group by channel interaction ($F_{(31, 3413)} = 3.55$, $p < 0.0001$). Both groups exhibited a pattern of synchronized theta activity concentrated over posterior-occipital electrodes although the low literacy group had a lower activity than the literate group (see Figure 13). Pairwise comparisons showed that there were no significant differences between groups at any specific electrode.

RM ANOVA of alpha (8-12 Hz) showed no significant effect of group ($F_{(1, 3430)}$ = 1.10, p = 0.295) but there was a significant effect of channel ($F_{(31, 3430)}$ = 11.89, p < 0.0001). There was also a significant group by channel interaction ($F_{(31, 3430)}$ = 2.03, p = 0.0006). Both groups exhibited a pattern of widespread desynchronized alpha activity with some concentration over central posterior-parietal electrodes although the low literacy group had less desynchronized activity than the literate group (see Figure 14). Pairwise comparisons showed that there were no significant differences between groups at any specific electrode.

RM ANOVA of beta (15-29 Hz) showed no significant effect of group ($F_{(1, 3342)}$ = 1.88, p = 0.171) but there was a significant effect of channel ($F_{(31, 3342)}$ = 12.42, p < 0.0001). There was also a significant group by channel interaction ($F_{(31, 3342)}$ = 3.70, p < 0.0001). The low literacy group exhibited a pattern of synchronized beta activity concentrated over frontal-temporal electrodes while the literate group had no concentrated activity (see Figure 15). However, pairwise comparisons showed that there were no significant differences between groups at any specific electrode.

Therefore, hypothesis H2 is partially supported.

H4: Effect of choice density on effort

There was no significant difference for the self-perceived effort (p = 0.295) between the lower choice density interface (0.41 ± 0.50 s) and the higher choice density interface (0.48 ± 0.50 s).

RM ANOVA of theta (5-7 Hz) showed no significant effect of interface type ($F_{(1, 3413)}$ = 0,00, p = 0.944) but there was a significant effect of channel ($F_{(31, 3413)}$ = 15.57, p < 0.0001). There was also no significant interaction between channel and interface type ($F_{(31, 3413)}$ = 0.93, p = 0.582).

RM ANOVA of alpha (8-12 Hz) showed no significant effect of interface type ($F_{(1, 3430)}$ = 2.82, p = 0.0933) but there was a significant effect of channel ($F_{(31, 3430)}$ = 11.89, p

< 0.0001). There was also no significant interaction between channel and interface type ($F_{(31, 3430)} = 0.26$, $p = 1.00$).

RM ANOVA of beta (15-29 Hz) showed no significant effect of interface type ($F_{(1, 3342)} = 0.01$, $p = 0.936$) but there was a significant effect of channel ($F_{(31, 3342)} = 12.42$, $p < 0.0001$). There was also no significant difference between channel and interface type ($F_{(31, 3342)} = 0.270$, $p = 1.00$).

Therefore, hypothesis H4 is not supported.

H6: Effect of literacy and choice density interaction on effort

There was no significant group by interface type interaction effect detected for the self-perceived effort ($F_{(1, 123)} = 0.02$, $p = 0.886$).

RM ANOVA of theta (5-7 Hz) showed no significant interaction between group and interface type ($F_{(1, 3413)} = 2.87$, $p = 0.090$) nor between group, channel, and interface type ($F_{(31, 3413)} = 0.62$, $p = 0.95$).

RM ANOVA of alpha (8-12 Hz) showed no significant interaction between group and interface type ($F_{(1, 3430)} = 1.01$, $p = 0.314$) nor between group, channel, and interface type ($F_{(31, 3430)} = 0.29$, $p = 1.00$).

RM ANOVA of beta (15-29 Hz) showed no significant interaction between group and interface type ($F_{(1, 3342)} = 0.900$, $p = 0.342$) nor between group, channel, and interface type ($F_{(31, 3342)} = 0.430$, $p = 0.997$).

Therefore, hypothesis H6 is not supported.

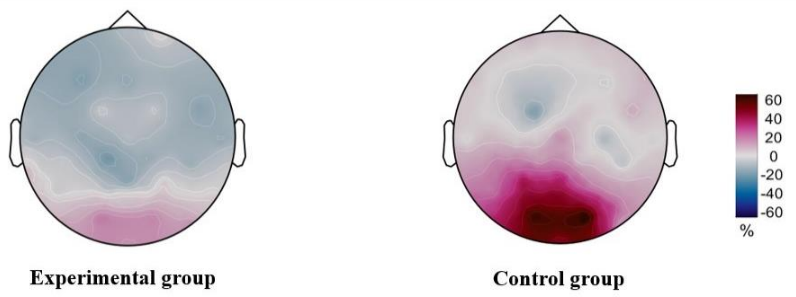


Fig. 13. EEG topography of theta (5-7 Hz) for the experimental group (left) and the control group (right). The key applies to both.

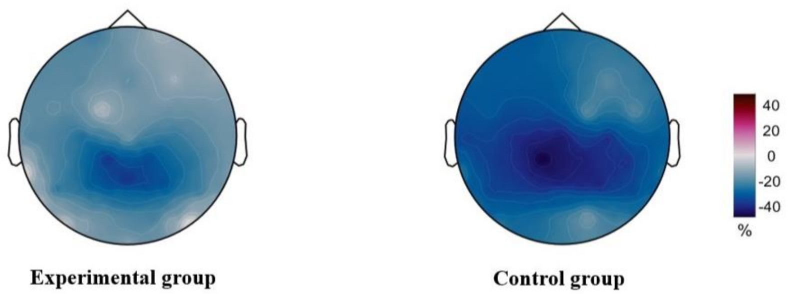


Fig. 14. EEG topography of alpha (8-12 Hz) for the experimental group (left) and the control group (right). The key applies to both.

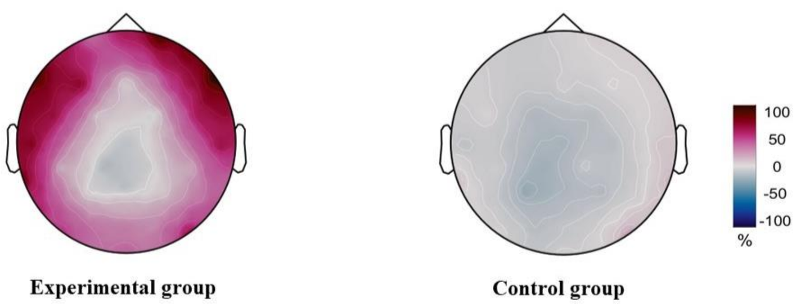


Fig. 15. EEG topography of beta (15-29 Hz) for the experimental group (left) and the control group (right). The key applies to both.

Table 5.

Summary of results grouped by hypotheses

Hypothesis	**Dependent Variable**	**Condition**	**Mean**	**Standard Error**	**P-value**	**Status**
H1	Response Time (seconds)	Low Literacy	11.21	1.14	p < .0001	Supported
		Literate	9.30	1.12		
	Success Rate	Low Literacy	0.98	0.80	p < .0001	
		Literate	1.89	0.47		
H2	Self-Perceived Effort	Low Literacy	0.76	0.43	p < .0001	Partially supported
		Literate	0.11	0.32		
	Theta (%)	Low Literacy	-7.03	46.20	p = .410	
		Literate	9.11	47.43		
	Alpha (%)	Low Literacy	-20.12	35.05	p = .295	
		Literate	-32.09	41.24		
	Beta (%)	Low Literacy	16.57	59.08	p = .171	
		Literate	-6.70	40.57		
H3	Response Time (seconds)	Higher Choice Density	9.85	1.49	p = .229	Not Supported

		Lower Choice Density	9.99	1.36		
	Success Rate	Higher Choice Density	1.50	0.71	p = .539	
		Lower Choice Density	1.42	0.85		
H4	Self-Perceived Effort	Higher Choice Density	0.48	0.50	p = .295	Not Supported
		Lower Choice Density	0.41	0.50		
	Theta (%)	Higher Choice Density	1.71	48.91	p = .944	
		Lower Choice Density	1.53	49.42		
	Alpha (%)	Higher Choice Density	-25.16	39.34	p = .0933	
		Lower Choice Density	-26.52	38.16		

	Beta (%)	Higher Choice Density	7.51	52.95	p = .936	
		Lower Choice Density	7.81	53.85		
H5	Response Time	Literacy by Choice Density Interaction	N/A	N/A	p = .868	Not Supported
	Success Rate	Literacy by Choice Density Interaction	N/A	N/A	Analysis did not converge	
H6	Self-Perceived Effort	Literacy by Choice Density Interaction	N/A	N/A	p = .886	Not Supported
	Theta (%)	Literacy by Choice Density Interaction	N/A	N/A	p = .090	
	Alpha (%)	Literacy by Choice Density Interaction	N/A	N/A	p = .314	
	Beta (%)	Literacy by Choice	N/A	N/A	p = .342	

		Density Interaction				

3.6 Discussion

The objective of this study is to improve the accessibility of a digital banking interface for a functional illiterate population without compromising the user experience of the broader customer base. Based on the choice overload theory, a prototype of a simplified version of a real digital banking interface was developed by reducing the number of possible choices (CTAs). A functional illiterate group (i.e., experimental group) and a control group then had to complete three real banking tasks on both the simplified version as well as the actual version of the interface so that their experience could be compared. Performance was measured through completion time and success rate during the tasks, and effort was measured through a self-perceived single-item effort scale and indices of electroencephalography (EEG) brain activity (theta, alpha and beta).

As hypothesized (H1), participants with low literacy had a worse performance during the tasks than those with a normal level of literacy reflected in higher completion times and lower success rates which is in line with many studies (Bramao et al., 2007; Mohammed et al., 2023b; Vágvölgyi et al., 2016; Viswanathan et al., 2005). However, contrary to the hypotheses, no significant differences were detected between the simplified and actual interface (H3) and no significant interaction was detected between the level of literacy and interface type (H5).

Similar results were found for effort, where, as hypothesized (H2), participants with low literacy reported a higher effort during the tasks than literate participants, and with, contrary to hypotheses, no effect of the interface type (H4) nor the interaction between the two (H6) was detected. Though it is different for the EEG results. Contrary to the hypothesis, neither the level of literacy (H2) nor the choice density of the interface (H4) nor their interaction (H6) affected any EEG frequency bands. There was a significant effect of channel and a significant group by channel interaction for all frequency bands although pairwise comparisons showed that there were no significant differences between groups at any specific electrode. For theta (5-7 Hz), the experimental group and the control group exhibited similar concentrated synchronized activity in the posterior-occipital regions with the experimental having lesser synchronization than the control group. For alpha (8-12 Hz), both groups also had a similar pattern of widespread desynchronized activity with some concentration over the central posterior-parietal regions though the experimental group had lesser desynchronization than the control group. For beta (15-19 Hz), only the experimental group exhibited a synchronized activity concentrated over frontal-temporal electrodes compared to the control group which showed no pattern of activity.

Concerning the research question “To what extent does reducing choice density on a digital interface affect the experience of functional illiterates compared to the general user?”, results show that the experience for both the functional illiterate and the control group is neither improved nor diminished by a reduction of choice density. However, there are many factors to consider that can moderate the effect of choice overload which may have been overlooked in the present study. Additionally, this could also suggest that altering the visual design might not be sufficient to improve the usability for a low literate population. For example, it has been suggested that icons, although they can improve visual affordance, have limited effectiveness especially when one is not familiar with their meaning. Studies have found that familiarity with the interface and its elements is an important factor in user performance as well as intuitive interaction (Lawry et al., 2019; Shen et al., 2020). Additionally, as seen in Viswanathan et al. (2015), functional illiterates tend to get confused and increasingly nervous when faced with an unfamiliar environment as any pattern or information they may have learned to help navigation no longer applies.

The EEG results also bring interesting insights as EEG studies involving functional illiterates, especially in a more ecologically valid environment are uncommon, and other tools such as magnetic resonance imaging and positron emission tomography are favored (Ardila et al., 2010; Bulajić et al., 2019; Petersson et al., 2001; Vágvölgyi et al., 2016). Theta and alpha results concord with previous studies supporting that functional illiterates have deficiencies in early visual processing and the use of attentional processes respectively. For alpha, studies assessing cognitive abilities through neurophysiological tests have found that functional illiterates have less proficiency in their attentional abilities.

Lesser event-related desynchronization of alpha, like the pattern of activity seen in Figure 14, has been linked to reduced use of attentional processes in visual tasks (Clayton et al., 2018; Klimesh, 1999). For theta, numerous neurophysiological studies have found that people with functional illiteracy or low literacy have reduced activity in the early visual processing regions, as seen in our results (Figure 13) and that these areas process the visual information less efficiently (Castro-Caldas, 2004; Dehaene et al., 2010; Pegado et al., 2014). This is most likely due to their lack of reading acquisition. Indeed, learning how to read has been shown to change the brain on a structural and functional level, improving the efficiency of numerous language-related processes and structures (Dehaene et al., 2015). However, the reduced activity in theta could also be caused by a lack of familiarity with the visual information on the interface. Indeed, although an increase in theta power has been linked to both the encoding of visual information as well as its retrieval, theta seems to be more strongly involved in the latter. Jacobs et al. (2006) recorded the EEG activity of participants during the Sternberg working memory task and found that left parietal theta power correlated with memory recognition. Klimesh et al. (2000) similarly found that parietal theta power increases in response to recognition of previously encountered stimuli. Numerous EEG studies also support this relationship between theta activity in the posterior regions and memory recollection (Fournier et al., 1999; Holz et al., 2010; Kotlewska et al., 2023). An argument could also be made that this theta activity is a sign of reduced cognitive load, however, the higher self-reported effort during the tasks by the functional illiterate group contradicts this. Given that functional illiterates tend to have lower digital literacy, it seems reasonable to believe that they do not often use digital interfaces for their banking transactions and therefore are not sufficiently familiar with the visual information to navigate on the website.

Beta results suggest that cognitive load and effort are increased during the tasks due to the deficiencies. But they also suggest functional illiterates might be compensating for these shortcomings through greater use of higher-order executive functions like Petersson et al. (2001). This is supported by a synchronized activity concentrated on the frontal regions (Figure 15) (Barsharpoor et al., 2021; Schmidt et al., 2019). Executive functions, such as working memory, cognitive flexibility, and inhibition, have been found to significantly contribute to reading comprehension and because effortful reading, as seen with functional illiterates, requires more resources, their role might be especially important for this population (Nouwens et al., 2021). First, they have a role in the top-down modulation of attentional control reflected in the inhibition of irrelevant information and the shifting of attention depending on the task (Altemeier et al., 2008). Second, high-order executive functions also serve as a top-down modulation of early visual processing by discriminating visually similar words through meaning (i.e., chair and chain) (Carreiras et al., 2009). However, because functional illiterates tend to have a limited vocabulary, the compensation using top-down processes might not be sufficient as seen by their lower performance during the tasks and higher self-reported effort. Again, familiarity with the interface could potentially be beneficial as it would reduce the need for conscious top-down influence during navigation since the steps needed to accomplish certain tasks would be known and remembered (Delorme et al., 2004).

3.7 Conclusion

In developed countries, there is a high prevalence of functional illiterate which is a deficiency in many skills necessary to function in society (Vágvölgyi et al., 2016). Because some of those skills include calculating and digital literacy, digital banking interfaces might not necessarily be accessible to this population which can increase the digital divide (Ahmed et al., 2019; Cree et al., 2012; Mohammed et al., 2023a). Throughout the years, studies have recommended many design features to improve the accessibility of digital interfaces for functional illiterates such as using pictographic elements and audio support (Islam et al, 2023). However, because the development of an interface made specifically for this population may be seen as stigmatizing (Knoche and Huang, 2012) and accessible design should consider the experience of all users, it would be more appropriate to alter actual digital banking interfaces. Therefore, since functional illiterates have been known to be easily overwhelmed by many choices on a digital interface (Chaudry et al., 2012), the purpose of the present study was to determine if reducing choice overload could improve the accessibility of a digital banking interface for a functional illiterate population while ensuring the experience of the broader customer base remains uncompromised. To achieve this, we developed a simplified version of a real banking interface by reducing the number of calls-to-action (CTAs) and comparing the user experience of both a functional illiterate group and a literate control group with the one on the actual interface. For this purpose, participants had to complete three real banking tasks on each interface, and their performance (completion time and success) as well as effort (self-reported scale, and cortical activity through EEG theta, alpha, and beta) was measured. Results show that the performance of the functional illiterate group was significantly worse than the control group reflected in higher completion time and lower success rate. They also show that the pattern of activity was significantly different between groups where the functional illiterate group had lower synchronized theta activity in the posterior regions, less widespread desynchronized alpha activity, and less synchronized beta activity in the frontal regions. Additionally, there was no significant effect detected of the number of choices of an interface on any of the measures.

3.7.1 Practical implications

Our results suggest that altering the visual design of an interface might not be a sufficient solution to improve accessibility for functional illiterates. Changing the digital interface has a risk of creating additional load for this group as seen when adding visual features such as icons that have been shown to have mixed effectiveness for a wide population. Instead, enhancing the general familiarity of functional illiterate users with the interface's important visual information and steps to accomplish essential tasks seems to be the most appropriate method to enhance accessibility.

Many possibilities exist to familiarize users with the interface, and each has its costs and benefits. For example, an online tutorial giving a detailed guide on how to accomplish common tasks (i.e. paying a bill, transferring money, etc.) could be created. However, although it might be less costly and more convenient, as it can be accessed from any device, designers need to make sure that the tutorial remains visible so that it is easily accessible for functional illiterates. Furthermore, in-person workshops could offer a more hands-on approach to learning and allow functional illiterate to get help when getting to know the interface. This would capitalize on their reliance on rote memorization when learning to accomplish tasks. But this method is also more expensive. Depending on the resources of the bank, one method might be more appropriate than another. In any case, collaborations with literacy foundations might be beneficial to the application of a method.

3.7.2 Limitations and research avenues

One important limitation of the present study is that the literacy level of participants could not be assessed due to time constraints. Although performance and effort differences suggest that participants came from two populations, this could have helped control heterogeneity within each group. Another limitation, again due to time constraints, is the lack of control for other factors that may have moderated the manipulation of choice density between interfaces. The use of more similar tasks, both in their complexity and their nature, could have helped in controlling some of these factors. Furthermore, the number of participants was small, which could have affected the statistical power of some analyses. However, the fact that the data comes from a unique group such as functional illiterates compensates for the small sample size. Additionally, the ecological validity of the study was reduced due to the use of prototypes instead of fully functional websites for the stimuli. This was also reduced because of the laboratory context and the use of EEG.

Future studies could compare the experience of functional illiterates and control subjects when using different onboarding methods with the digital banking interface and how it impacts their performance. Additionally, because familiarity seems to be an important factor in the experience of functional illiteracy, future studies could see the effect of the gamma (30-70 Hz) frequency band of interest due to its relationship to familiarity compared to recollection (Gruber et al., 2008).

3.7.3 Final Remarks

It can be challenging to create accessible interfaces that consider the needs of a group such as functional illiterates. Our results suggest that altering the visual design of an interface might not be enough to improve their experience, nor that of the general population. Instead, increasing familiarity with the information on a website might be a more effective method to ensure an optimal user experience. However, future studies are needed to properly evaluate the effects of familiarity on the experience of functional illiterates. The present study contributes to the current accessibility research and provides a deeper understanding of the neurophysiological processing of information in functional illiterate populations.

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Chapitre 4 : Conclusion

L'objectif de ce mémoire était d'améliorer l'accessibilité des interfaces bancaires numériques pour les analphabètes fonctionnels sans nuire à l'expérience de l'ensemble de la clientèle. Les questions de recherche pour cette étude sont les suivantes :

QR1 : Est-ce que les représentations iconographiques sont efficaces pour améliorer l'accessibilité des interfaces bancaires chez une population d'analphabètes fonctionnels?

QR2 : Dans quelle mesure la réduction de la densité des choix sur une interface numérique affecte-t-elle l'expérience des analphabètes fonctionnels par rapport aux utilisateurs généraux ?

4.1 Résultats principaux

Les résultats des articles suggèrent que l'accessibilité des interfaces bancaires numériques pour les analphabètes fonctionnels ne s'améliore pas efficacement par le design visuel de l'interface, mais plutôt en augmentant la familiarité avec ses informations importantes.

Pour l'article 1, l'étude cherchait à évaluer le traitement neurophysiologique des icônes et des mots en utilisant une tâche contrôlée de recherche visuelle et l'électroencéphalographie (EEG) afin de déterminer si les icônes étaient efficaces avec les analphabètes fonctionnels. Les résultats suggèrent que, même si elles augmentent l'affordance visuelle, la signification des icônes peut être trop ambiguë rendant leur interprétation difficile autant pour les analphabètes fonctionnels que pour un groupe contrôle. Les résultats EEG de l'onde thêta suggèrent aussi que le manque de familiarité avec les stimuli peut interférer avec l'efficacité de leur traitement chez les analphabètes fonctionnels. Les icônes par eux-mêmes ne sont donc pas suffisantes pour améliorer l'accessibilité d'une interface, et ce, pour n'importe quel groupe d'utilisateurs.

Pour l'article 2, l'étude cherchait à comprendre dans quelle mesure une réduction de la densité de choix sur une interface, à travers une réduction du nombre d'éléments call-to-action (CTA), affectait l'expérience des analphabètes fonctionnels, et ce, en demandant aux participants d’effectuer de vraies tâches bancaires sur un site web bancaire ainsi que sa version simplifiée. Les résultats n’ont pas détecté de différence ni dans la performance ni dans l’effort nécessaire pour accomplir les tâches entre les deux interfaces suggérant que la manipulation de la densité de choix n’a pas d’effet. Cependant, les résultats EEG de l’onde thêta suggèrent que les analphabètes fonctionnels ne sont pas familiers avec l’information visuelle sur l’interface et ont donc de la difficulté à traiter efficacement cette information. Les résultats de l’onde bêta suggèrent que les membres de ce groupe compensent pour cette limite, avec peu de succès, en utilisant leurs fonctions exécutives de haut niveau (raisonnement et résolution de problèmes).

En somme, les deux articles suggèrent qu’un changement du design visuel d’une interface numérique n’est pas suffisant pour améliorer l’expérience des analphabètes fonctionnels. Leur manque de familiarité avec les éléments numériques, dû à un bas niveau de littératie numérique répandu dans ce groupe, annule les potentiels avantages que peuvent offrir ces changements visuels tels que l’utilisation d’icônes pour améliorer l’affordance. Ce faible niveau de familiarité peut être observé à travers l’activité neurophysiologique des analphabètes fonctionnels, et ce, autant lors d’une tâche contrôlée (article 1) que lors d'une tâche naturelle (article 2). En effet, l’activité EEG de l’onde thêta suggère que le traitement de l’information visuelle chez les analphabètes fonctionnels est moins efficace comparé à une population de contrôle. Il est probable que cette réduction de l’efficacité soit due à un manque de familiarité avec les stimuli visuels. Ainsi, même si l’information sur l’interface est réorganisée ou des éléments comme des icônes sont ajoutés pour améliorer la compréhension des mots, l’expérience ne se verra pas améliorée. La familiarisation avec les éléments du site web et, surtout, avec les étapes nécessaires pour accomplir des tâches importantes est plus propice à assurer une meilleure expérience utilisateur, non seulement pour les analphabètes fonctionnels, mais potentiellement pour d’autres groupes ayant des difficultés similaires. Des tutoriels en ligne par exemple pourraient aider les utilisateurs à bien connaître l’interface.

4.2 Contributions

Cette section décrit les différentes contributions du mémoire.

4.2.1 Contributions théoriques

Comme contributions théoriques, le mémoire s'ajoute à la littérature concernant l'accessibilité des interfaces numériques pour les analphabètes fonctionnels. Il offre des connaissances sur l'effet de la manipulation de différents types d'éléments d'une interface bancaire numérique sur l'expérience utilisateur autant des analphabètes fonctionnels que d'un groupe contrôle. L'impact de ces éléments de design (les icônes et la densité de choix) a pu être évalué dans son ensemble : au niveau comportemental et au niveau neurophysiologique. Le mémoire contribue aussi à la compréhension des processus neurophysiologiques des analphabètes fonctionnels lors du traitement de l'information visuel, surtout que les études avec cette population contenant de l'électroencéphalographie (EEG) sont rares. Les résultats permettent notamment de mettre en lumière l'importance de la familiarité sur l'efficacité du traitement visuel ainsi que l'utilisation des fonctions exécutives comme forme de compensation lorsque des stimuli moins connus sont rencontrés.

4.2.2 Contributions pratiques

Les résultats du mémoire ont des utilités pratiques pour les organisations dans le domaine bancaire puisqu'ils permettent d'améliorer l'accessibilité de leur interface. En effet, les études menées suggèrent que les icônes ne sont pas suffisantes pour améliorer l'accessibilité et il en est de même pour la réduction de la densité de choix (le nombre de boutons) sur une page. De plus, les deux articles supportent l'idée que plutôt que mettre l'accent sur le design visuel de l'interface, il faut s'assurer que les utilisateurs, particulièrement les analphabètes fonctionnels, soient familiers avec les informations importantes sur le site. Les organisations peuvent donc se concentrer sur le développement, l'évaluation et l'implémentation des méthodes qui favorisent cette familiarisation avec l'interface numérique.

Cependant, les résultats ont la possibilité de se généraliser à plusieurs domaines. Comme avec les banques, les organisations offrant des services essentiels peuvent se baser sur les résultats pour rendre leur interface plus accessible. Les résultats peuvent potentiellement aussi fournir des indications pour venir en aide à d'autres groupes vivant des difficultés similaires avec les interfaces numériques, comme les personnes âgées.

4.3 Discussion

Les analphabètes fonctionnels formant une grande partie de la population, il devient important de s'assurer que les interfaces bancaires numériques restent accessibles à ce groupe afin de favoriser leur intégration et réduire le fossé numérique. Les résultats suggèrent que changer le design visuel d'une interface, que ce soit en ajoutant des icônes ou en réduisant la densité de choix (le nombre de boutons), n'est pas suffisant pour la simplifier, et donc, améliorer l'accessibilité. La familiarité avec l'interface semble être un facteur plus important sur lequel les entreprises devraient mettre plus d'accent.

4.3.1 Limitations

Il y avait principalement trois limitations générales pour ce mémoire. À cause des contraintes de temps, il n'était pas possible d'évaluer le niveau de littératie des participants empêchant ainsi de contrôler pour l'hétérogénéité dans les groupes. Cependant, dans les deux articles, les différences significatives de performance entre les groupes suggèrent que le groupe d'analphabètes fonctionnels et le groupe contrôle étaient bel et bien distincts. De plus, le nombre était petit, ce qui a potentiellement affecté la puissance des analyses. Mais, l'opportunité de conduire une expérience avec un groupe d'analphabètes fonctionnels est rare, d'autant plus pour une étude utilisant le EEG, montrant la valeur des données collectées et des résultats. Le contexte expérimental et l'utilisation de EEG ont aussi diminué la validité écologique de l'étude. Pour l'article 1 spécifiquement, une autre limitation de l'étude est que les potentiels évoqués (ERPs) n'ont pas été comparés entre les groupes ce qui pouvait être pertinent dans une tâche de recherche visuelle dont les essais étaient rapides. Pour l'article 2, les contraintes de temps ont empêché de contrôle pour d'autres facteurs pouvant influencer la manipulation de la densité de choix sur les interfaces.

4.3.2 Avenues de recherche

Comme la familiarité semble être un facteur important pour les analphabètes fonctionnels, les études futures pourraient explorer l'effet de différentes méthodes d'accueil ainsi que leurs impacts sur l'expérience utilisateur de cette population. L'expérience entre d'autres groupes vivant des difficultés similaires avec les interfaces, comme les personnes âgées, pourrait aussi être comparée afin de déterminer si une méthode est plus généralisable. De plus, pour les études EEG, les effets de ces méthodes sur la bande de fréquence gamma (30-70 Hz) pourrait être exploré dû à son lien avec la familiarité (Gruber et al., 2008).

4.3.3 Remarques finales

La recherche en accessibilité devient de plus en plus essentielle dans un monde qui repose sur la technologie. Elle permet non seulement d'aider une population avec des besoins spécifiques, mais potentiellement d'autres groupes pouvant vivre les mêmes difficultés avec les outils numériques. Il est important d'assurer la meilleure expérience utilisateur pour l'ensemble des utilisateurs, mais l'impact sur la qualité de vie reste au cœur de la recherche en accessibilité.

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