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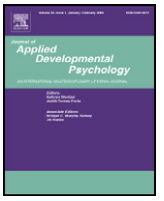

Spelling and the Web

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ABSTRACT

Correct spelling is increasingly important in our technological world. We examined children's and adults' Web search behavior for easy and more difficult to spell target keywords. Grade 4 children and university students searched for the life cycle of the lemming (easy to spell target keyword) or the ptarmigan (difficult to spell target keyword). Children's search strategies were more variable and less effective than were adults', especially when they could not spell the target word correctly. Our findings demonstrate the need for search programs to include a true dictionary to assist with spelling keywords as well as the need to teach children and adults more effective Web search strategies. They also begin to extend recent research and theory on children's strategy development to a new domain of Web searching.

1. Introduction

Correct spelling is important in our technological society, especially for Web-based information search and retrieval. For example, a child looking in a print encyclopedia of birds for information about ptarmigan (a small, arctic bird that looks like a grouse), after failing to find entries under *tarmigan* or *tarmagan*, may resort to browsing through the pages and inspecting all the photographs and entries in the book. This strategy is extremely time consuming and the utility of the strategy decreases as a function of the length of the book. As another information source, the Web is much too large to make a similar browsing strategy feasible (Kuiper, Volman, & Terwel, 2005; Varnhagen, 2002). The Web is also nonlinear in nature so even finding appropriate pages to browse would be a daunting task for a child.

However, despite the potential difficulties associated with finding information on the Web, children are increasingly using it to search for information for school reports or for personal reasons (Varnhagen, 2007). Close to 50% of Canadian Grade 4 children use the Web for homework and this percentage increases with age (Spears, Seydegart, & Zulinov, 2005); however, few studies have examined children's search behavior and spelling associated with searching. In an early study of searching online library catalogues, Borgman, Hirsch, Walter, and Gallagher (1995) found spelling to be significantly related to search success. Children who could not spell the keyword they were searching for in the online catalogue were unsuccessful in finding the associated information. However, if the children were familiar with the term they were searching for, they were sometimes able to refine their search to find the relevant information. For example, some children who knew about dinosaurs abandoned searching for *tyrannosaurus*, which they had trouble spelling, and searched for *dinosaur* instead. On the other hand, few children were familiar with the term, *veterinarian*, and did not attempt alternative approaches to searching when they could not spell the keyword.

Bilal (2000, 2001, 2002) investigated junior high school students' Web search behavior using different tasks. Even given the correct spelling for the search tasks, some children still misspelled the target keywords. Based on her observations, Bilal argued that search programs should include spell-checking features. Supporting this conclusion, Large, Beheshti, and Rahman (2001), engaged in user-centered design research with older children and adolescents. Although the participants themselves did not indicate a strong preference for spell-checking, Large et al. concluded that spell-checking should be a feature of Web portals

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designed for young people. Proctor (2002) reviewed ways in which misspelling has been used profitably on the Web, including the now less frequent technique of "mousetrapping," where slight spelling alterations can lead to pornographic sites, such as searching for "sinderella" or "barby." He argued that, to provide maximal results, search programs should provide results for multiple spellings of the entered keywords.

Recognizing difficulties in searching with incorrect spelling, many search programs, such as Google, MSN, and Ask.com, have created dynamic dictionaries to support spelling errors. While searching its database for the requested keywords, the search program also searches for alternative spellings of the keywords. If an alternative spelling yields more results than the requested spelling, the program prompts with "Did you mean:" or "Were you looking for." Thus, using Google as an example, if a user searches for the keyword, *ptarmigen* and there are more database entries for *ptarmigan* than for *ptarmigen*, then the program will return results for *ptarmigen* but query, "Did you mean: ptarmigan" with a link to a search for *ptarmigan*.

These search program dictionaries are not true dictionaries, however, based on definitions, pronunciations, and etymology, but are created as part of the indexing process. A Web crawler is an automated process that collects and indexes Web pages for search engines. The Web crawler collects text on the Web page to include in the database of the search program. The Web crawler collects all text — correct and incorrect spellings and multiple meanings — into a large database for indexing. The collected text also comprises the dictionary (Schneider, Blachman, & Fredricksen, 2003). Thus, when the Web crawler encounters a Web page created by a camping company, "Tarmigan Campgrounds," the program enters *tarmigan* and *campground* into the dynamic dictionary, along with the address of the Web page. If the Web crawler encounters disparate spellings, such as *tarmigan* and *ptarmigan*, both are entered into the dynamic dictionary.

In addition to the dynamic database, the Google dictionary uses a combination of unigram, bigram, and trigram frequency counts for checking alternative spellings against the database of common spellings (Brill & Cucerzan, 2004; Golding & Roth, 1999). For example, searching Google for *tarmigen* will yield, "Did you mean: tarmigan" but it will not yield, "Did you mean: ptarmigan" because *ga* is a much more frequent bigram than *pt*. Thus, the child searching for *tarmigen* will never be asked "Did you mean: ptarmigan" even though there are over a million more results for the keyword, *ptarmigan*, than there are for *tarmigan*. In defense of these frequency algorithms, however, many misspellings do differ according to common unigrams, bigrams, or trigrams. For example, from the close to 600 misspellings of Britney Spears (http://www.google.com/jobs/britney.html), most differ by common bigrams, e.g., *Brittney Spears* or *Britany Spears*, and, to the immense benefit of young fans, are easily caught by the search program dictionary.

Given the limits of the search spell checker, does spelling affect search behavior? What alternative strategies do children and adults use when they cannot spell a search term correctly? Are these alternative strategies effective for Web searching? Can children and adults who are skilled Web searchers use their Web skills to find information even if they cannot spell the keywords that comprise their search?

Research into how users search for information on the Web when they cannot spell the keywords is important for designing useful Web search interfaces and programs. Once we know how users of different ages find and fail to find information on the Web, we can begin to design an interface to support their information searches. As well, once we know how successful searchers find information on the Web, we can begin to develop educational interventions to help children and beginning Web users learn to find information on the Web effectively and efficiently.

This research is also important for understanding strategy use in the domain of Web searching. A number of researchers have studied strategy development, use, and generalization in cognitive domains, such as understanding strategy use on the balance beam task (e.g., Jansen & van der Maas, 2002), and in academic domains, such as arithmetic (e.g., Siegler & Shrager, 1984; Siegler & Jenkins, 1989) and spelling (e.g., Kwong & Varnhagen, 2005; Rittle-Johnson & Siegler, 1999). These researchers have considered how children and adults approach a task with a repertoire of strategies and how development leads to the selection of more effective and efficient strategies from this repertoire. Building on the previous research on overlapping waves perspectives of strategy development (cf., Siegler, 2006; Siegler & Jenkins, 1989), we were interested in how children and adults adapt their search strategies when they are unable to spell the target keyword.

Grade 4 and undergraduate students participated in this study. According to the curriculum guide for the school jurisdiction we used, children in Grade 4 are beginning to access and to use Web-based information in their school reports. According to Yan (2005), Grade 4 children are also just beginning to develop a naive understanding of the Internet. The undergraduate students, by contrast, represented a relatively expert group (Yan, 2005). We also administered a brief computer and Internet skills questionnaire to examine within group influence of experience on Web searching. Participants who are experienced Web searchers may approach searching for information without correct spelling differently than participants who are not as experienced at searching the Web.

Participants searched for information on the life cycle of a lemming or a ptarmigan; this represented a familiar task for the elementary school children. We considered *lemming* to be an easy-to-spell word; it was also one for which common misspellings, such as *leming*, would yield a correct alternative spelling suggestion. We considered *ptarmigan* to be a difficult-to-spell word and one that, unless the participant could spell the silent initial letter, would not yield a correct alternative spelling suggestion. We did not request that participants find "the best" Web resources, only that they find a resource they could use in a school report. Thus, this study emphasized *finding* Web resources, not *critically appraising* Web resources (cf. Varnhagen, 2007).

We analyzed how children and adults changed their keyword search expression — or engaged in other search behavior — when they were unsuccessful in finding the appropriate information. Based on the literature with children's strategy development, we hypothesized that children would display variability in search strategies but that they would take longer to complete the task and be less successful in completing the task than undergraduate students. Our primary interest, however, was how the participants would respond to spelling errors. If children are less aware or less able to modify their spellings for the keywords, they may be more likely to abandon one search strategy, such as *tarmigan life sikle*, for another ineffective search, such as *life sikle*. Adults, on the other hand, might follow reasonable alternative spelling suggestions, attempt to find the correct spelling through use of an on-line dictionary, or attempt different spellings of the word.

2. Method

2.1. Participants

We tested both children and adults. The children were 39 Grade 4 students (21 females and 18 males, *M* age = 9 years 6 months, *SD* = 6 months) recruited from two elementary schools using an information letter sent home through their school. The adult group consisted of 33 university students (18 females and 15 males, *M* age = 19 years, *SD* = 1 year, 6 months) recruited from introductory psychology courses at the University of Alberta who received course credit for participation.

We discarded the results of one of the Grade 4 participants in the ptarmigan search group. The participant used a spelling that, on the fourth result of the Google search, yielded a site with the description, "best sex/love scene…" The researcher terminated the session immediately, as outlined in our ethics protocol. The participant did not actually access the site. The researcher debriefed the participant and informed the child's teacher and parents of the situation.

2.2. Materials

2.2.1. Participant spelling and Web skills assessment

We assessed spelling ability using the Blue Spelling subtest of the WRAT3 (Wilkinson, 1993). The spelling test includes 40 words that start with simple words and get progressively more difficult.

We developed a computer and Web use survey to assess participants' computer and Web comfort. There were 15 questions on Web use (e.g., How frequently do you use the computer? How much do you trust information that you find on the Web?), and two questions addressing demographic information (e.g., birthday and sex). Table 1 shows our Web use survey items. The first item, concerning a home Internet connection, and the search items (e.g., search for games, search for information for school) items required a yes/no response. The other items required a response to a 5-point Likert scale.

2.2.2. Search task

The search task was performed on computers equipped with a mouse and a microphone. For school participants the computers were laptops with 15 in. monitors; for adults, we used desktop computers with 17 in. monitors. Audio and on-line activity were recorded with Camtasia software (http://www.techsmith.com/camtasia.asp). The school district had filtering and blocking software associated with all Internet connections made by the children in the district.

We selected lesser-known target animals for the search task and then tried out our choices using various search programs to determine the effect of different misspellings on the behavior of the program. We selected *lemming* and *ptarmigan* because all search programs made appropriate suggestions for misspellings of lemming but not for misspellings of ptarmigan (unless we included the correct first letter). We selected Google as our search program because (a) it is commonly used in our schools, (b) it has few ads, (c) it uses a ranking algorithm and does not move ads up in the results list for a fee, and (d) with the moderate filtering preference selected, it did not yield any unsafe results in our tests (but see the Participants section for one instance where a potentially pornographic site was obtained during testing).

2.3. Design and procedure

Participants in each of the two age groups (children, adults) were randomly assigned to search for the easy-to-spell word, *lemming*, or the difficult-to-spell word, *ptarmigan*.

We tested the children in two sessions; children first completed the search task in an individual 20 min session and later completed the spelling test and survey in small groups. Undergraduate students were tested in a single, 30–40 min individual session that included the search task, the spelling test, and the survey.

Table 1
Responses to the computer survey, reported as percentages.

Item	Adult	Child
Have Internet connection at home	97	95
Like using computer	88	71
Use computer frequently	88	61
Skill at using computer	48	61
Like searching the Web	39	50
Search the Web frequently	48	42
Skill at searching the Web	30	53
Search for entertainment	91	84
Search for school information	94	53
Search for other information	73	71
Search for chat/discussion	3	13
Trust information on the Web	9	53
Trust information in books	91	63
Trust information on television	21	26
Trust information in newspapers	45	68

Note: *N* = 39 children and 33 adults.

Table 2
Means (and standard deviations) for measures of search behavior as a function of age group and search task.

	Adult		Child	
Measure	Lemming	Ptarmigan	Lemming	Ptarmigan
Number of searches	2.7 (1.5)	8.5 (6.4)	3.8 (3.7)	8.7 (3.4)
Number of spellings	1.1 (0.3)	2.8 (1.5)	1.9 (0.9)	3.5 (1.9)

Note: $N = 39$ children and 33 adults.

2.3.1. Web search task

The researcher set the Web browser to the Google home page. The researcher told the participant that he or she was interested in how people search for information and instructed the participant to search for information on the life cycle of the lemming/ptarmigan that could be used in a school report. The participants were asked to say out loud what they were doing and why while searching. The researcher then started the Camtasia recorder and told the participant that he or she would have about 15 min to find the information. If the participant had not completed the search task in 15 min, the researcher terminated the session. In some cases, the participant kept searching until the researcher turned off the recorder and took control of the computer.

2.3.2. Spelling test and survey

Adults completed this task individually, while children completed this task in small groups of five or six. The participants spelled all 40 words in the Spelling Subtest of the WRAT. The researcher read the word, then read a sentence containing the word and finally repeated the word. If they did not know the spelling, they were instructed to take their best guess. Upon completion of the spelling task, participants completed the survey on computer and Web use.

3. Results

3.1. Participant characteristics

All participants had average to above average spelling ability based on their scores on the Spelling Subtest of the Wide Range Ability Test (WRAT3; Wilkinson, 1993); the mean standardized score for the children was 109.1 ($SD = 13.6$) and the mean score for the university students was 105.4 ($SD = 7.8$).

All participants reported that they were relatively computer and Web savvy on our computer and Web use survey shown in Table 1. The statistics in the table represent percentage of participants responding "Yes" to the yes/no items or "4" or "5" on the 5-point scale.

Adults and children made comparable responses to the survey, with the exception of frequency of use of computers, searching for information for school, and trust of information found on the Web and in books. We collapsed the frequency of computer use item and the trust items into two categories, representing responses of "1" to "3" and "4" to "5" on the 5-point scale. Adults reported using computers more frequently than did the children, $\chi^2\ (1) = 6.7$, $p < .01$. Adults also used the Web more frequently to search for school information, $\chi^2\ (1) = 14.5$, $p < .001$. In addition, adults reported trusting information from the Web less, $\chi^2\ (1) = 14.7$, $p < .001$, and information in books more, $\chi^2\ (1) = 9.2$, $p < .01$, than did children.

3.2. Search behavior

Measures of search behavior included number of searches and numbers of spellings. We defined the *number of searches* a participant performed as the number of times the participant typed in keywords and clicked on the Search button in Google. We defined *number of spellings* as the number of different spellings produced for the target keywords, such as *leming* or *tarmigen*, including the correct spelling of the target. Descriptive statistics for these measures are found in Table 2.

Separate analyses of variance, with age group (child, adult) and search task (*lemming* or *ptarmigan*) as group factors showed that participants conducted over twice as many searches for ptarmigan ($M = 8.5$ searches, $SD = 4.9$) as for lemmings ($M = 3.3$ searches, $SD = 3.0$), $F(1,67) = 29.4$, $p < .001$, and that they made more spelling attempts for ptarmigan ($M = 3.3$ spellings, $SD = 1.9$, such as *tarmigan*, *tarmegan*, *tarmgin*) than for lemming ($M = 1.5$, $SD = 0.8$, most often *leming*), $F(1,67) = 27.5$, $p < .001$. Interestingly, overall, children made no more spelling attempts than did adults.

When participants were unsuccessful on their first search, they made one or more changes to their search expression. We classified search expression changes into five categories, including: (1) *target keyword spelling* when a participant changed the spelling for the target keyword (e.g., changing from *leming* to *lemmings*); (2) *other keyword spelling* when a participant changed the spelling for one of the other keywords (e.g., from *life sicle* to *life cycle*); (3) *keyword expression* when a participant changed the entire search expression (e.g., from *life cycle leming* to *leming* "*life cycle*"); (4) *follow* "*Did you mean*:" when a participant clicked on the "Did you mean:" option; and (5) *other* when a participant engaged in some other search behavior, such as using another search engine (e.g., changing from Google to Yahoo!), checking an online dictionary (e.g., Dictionary.com), or typing in possible URLs (e.g., *www.leming.com*). Participants sometimes made more than one change at a time, such as changing the spelling of the target as well as changing the search expression (e.g., changing from *leming life cycle* to *life cycle lemming*). We considered each of these changes in search expression to represent a different search strategy.

Six adults and one child in the lemming search condition were successful on the first search and were therefore not included in the search change analysis. The mean number of changes in search expressions for children and adults in the lemming and ptarmigan search tasks are shown in Table 3.

We analyzed changes in search expression using a repeated measures analysis of variance with search expression change as a within-group factor and age group and search task as between group factors, with a Geisser-Greenhouse correction on the repeated measures. There was no difference in the number of different types of search expression changes made by children ($M = 2.6$, $SD = 1.4$) and adults ($M = 2.3$, $SD = 1.2$) but there was a significant effect of search task, $F(1,60) = 18.6$, $p < .001$. Children and adults used a greater range of changes on the more difficult ptarmigan search task ($M = 3.1$, $SD = 1.2$) than on the lemming search task ($M = 1.8$, $SD = 1.0$). We also found a difference in type of expression change, $F(4,240) = 18.3$, $p < .001$ that was qualified by an interaction between age group and type of change, $F(4,240) = 5.3$, $p < .01$. Decomposing the interaction using Tukey post hoc analyses showed that adults changed the entire expression ($M = 3.7$, $SD = 3.8$) more than three times as often as they made any other change ($Ms = 0.3–0.9$, $SDs = 0.5–1.2$), $HSDs = 14.7–17.9$, $p < .01$. Children, on the other hand changed the spelling of the target keyword, changed the entire search expression, or clicked the "Did you mean:" link approximately equally as often ($Ms = 1.2–1.4$, $SDs = 0.8–2.6$) and more often than they changed the spelling of other keywords or engaged in another type of change ($M = 0.4$ and 0.8, $SD = 0.9$ and 1.8, respective), $HSDs = 3.75–6.25$, $p < .01$.

Children's following of the "Did you mean:" link needs to be tempered by the number of times the option was presented, however. Google provided a "Did you mean:" result for 42% of children's searches and 21% of adults' searches; children clicked on the offered link 50% of the time and adults clicked on the link 59% of the time. Thus, children and adults responded to "Did you mean:" at approximately equal rates.

We examined type of change made from one search to the next. For example, in one search a participant could change the target keyword spelling (e.g., from *tamigen* to *ptarmigan*) and in the next search the participant could change the entire search expression (e.g., to *life cycle ptarmigan*). A participant could change the entire search expression in one search (e.g., from *tarmigan life cycle* to *tarmigan wildlife*) and change it again in the next search (e.g., to *tarmigan lifespan*). Consistent with the number of changes made as a function of type of search expression, children moved from one search to the next by changing the spelling of the target keyword 31% of the time (e.g., from *tarmigan* to *tomigen*) and changing the entire search expression 28% of the time (e.g., from *cycle the tomigan* to *life cycle of the tomigan*). Interestingly, those children who were ultimately successful in the search task changed the entire search expression less often than did children who were not successful (13% versus 34% for successful versus unsuccessful children) and changed the spelling of the target keyword more often (48% versus 22%) or clicked on "Did you mean:" (23% versus 13%). Adults, by contrast, made changes to the entire search expression from one search to the next 65% of the time and there were no differences in changes in search behavior as a function of eventual search success. Although suggestive of different patterns of search change strategies, we could not analyze these differences further because of dependencies within the data due to repeated counts.

3.3. Search success

We defined *search success* when the participant obtained appropriate search results, namely a Web site with information about the target animal that could be used in a school report. In all successful searches, participants ultimately found the information through successful spelling of the target keyword. As we expected, adults and children were mostly successful in searching for the easier-to-spell keyword, lemming, and were less successful in searching for the more difficult-to-spell keyword, ptarmigan. All adults (100%) and all but one child (95%) were successful with lemming and 10 of 17 adults (59%) and four of 19 children (22%) were successful with ptarmigan, Exact test $p < .05$.

We also analyzed changes in search expression as a function of age group and success or failure in the search task in a two between subjects (age group and success/failure) by one within subject (strategy change) repeated measures analysis of variance, using a Geisser-Greenhouse correction on the repeated measure. Because so many participants were successful on the lemming search and so few children were successful on the ptarmigan search, we collapsed across search task. The mean number of changes made as a function of age group and search success is shown in Table 4. Consistent with the previous analysis of search behavior, we found significant effects of strategy change, $F(4,240) = 28.4$, $p < .001$, success $F(1,60) = 27.3$, $p < .001$, and an age group by type of search expression change interaction, $F(4,240) = 9.6$, $p < .001$.

We also found an interaction between success or failure and type of search expression change $F(4,240) = 7.0$, $p < .001$. Decomposing the interaction using Tukey post hoc tests showed that participants who were unsuccessful at the search task changed the entire search expression ($M = 4.3$, $SD = 4.5$) more often than any other change ($Ms = 0.8–1.9$, $SDs = 0.9–2.3$), $HSDs = 8.9–13.3$, $p < .01$. Children and adults who were ultimately successful in the search attempted a range of search expression changes ($Ms = 0.2–1.7$, $SDs = 0.3–1.9$).

Table 3
Means (and standard deviations) for search expression changes as a function of age group and search task.

	Adult		Child	
Search expression change	Lemming	Ptarmigan	Lemming	Ptarmigan
Target keyword spelling	0.1 (0.3)	1.4 (1.3)	0.7 (1.1)	2.2 (1.9)
Other keyword spelling	0.0 (0.0)	0.4 (0.6)	0.3 (0.8)	0.6 (1.0)
Keyword expression	2.1 (1.0)	4.7 (4.5)	1.2 (2.5)	2.4 (2.6)
Follow "Did you mean:"	0.3 (0.5)	0.7 (1.0)	0.9 (0.5)	1.4 (1.0)
Other	0.2 (0.4)	0.6 (1.4)	0.1 (0.5)	1.6 (2.3)

Note: $N = 39$ children and 33 adults.

Table 4
Means (and standard deviations) for search expression changes as a function of age group and search success.

	Adult		Child	
Search expression change	Success	Failure	Success	Failure
Target keyword spelling	0.6 (1.1)	1.9 (1.2)	1.1 (1.8)	1.9 (1.4)
Other keyword spelling	0.2 (0.2)	0.4 (0.5)	0.2 (0.7)	0.8 (1.1)
Keyword expression	2.8 (2.2)	6.4 (5.9)	0.8 (0.8)	3.3 (3.5)
Follow "Did you mean:"	0.6 (0.9)	0.4 (0.5)	1.0 (0.7)	1.5 (1.0)
Other	0.2 (0.4)	1.1 (2.2)	0.1 (0.2)	1.9 (2.4)

Note: $N = 39$ children and 33 adults.

These analyses demonstrate that participants arrived at a successful spelling in many different ways. We examined the final change in search expression that led to search success. Again, because so few children were successful with the ptarmigan search, we collapsed across search task in our analysis. In no case did changing another keyword in the expression or engaging in another type of change lead to success so we excluded these categories from the analysis. Thus, our analysis of successful search strategy was a chi-square difference analysis, considering differences in frequencies of changing spelling versus changing the search expression versus following the suggested "Did you mean:" spelling for children versus adults. Adults and children differed in terms of what type of change in search yielded success, $\chi^2\ (4) = 17.4$, $p < .01$. When participants achieved success, it was not generally through correctly changing the spelling of the target word; only 12% of successful children and 9% of successful adults changed the spelling of the target keyword. When children were successful in the search task, they achieved success 69% of the time by following the "Did you mean:" link to the correct spelling. By contrast, 77% of successful adults changed the entire search expression.

Because adults were successful with search expression changes, we analyzed the way in which the search expression was changed. We categorized expression changes as *add* words or Boolean terms (e.g., changing from *lemming* to *life cycle lemmings*), *remove* words or Boolean terms (e.g., changing from "*life cycle of lemming*" to *life cycle lemming*), *change the surrounding words* (e.g. changing from *Where does ptarmigan live*? to *ptarmigan life cycle*), change the word order (e.g., changing from *life cycle tarmigan* to *tarmigen life cycle*), and *remove the target keyword* (e.g., changing from *tarmigan* to *arctic bird*). The most frequently occurring search expression changes were to *add* words (33% of adults' and 45% of children's search expression changes), *remove* words (32% and 23% for adults' and children's expression changes), and *change the surrounding words* (28% for both adults' and children's search expression changes). Whether a search expression change was successful or not was extremely idiosyncratic. Search expression changes that resulted a successful outcome included adding words to the expression (33% of the successful changes for adults), such as changing from *lemming* to *life cycle lemmings*, which narrowed down the number of results and included the actual information being sought, and removing words and Boolean terms from the search expression (40% of the successful changes for adults), such as changing from *science life cycle leming OR lemm* to *life cycle lemming*, which increased the number of results but included the information being sought. Children were much less likely to be successful by changing their search expression but the same pattern held for the few children who did achieve success by changing the expression, such as the child who removed a word from the search expression, changing from *lemmings families* to *lemmings*.

3.4. Target keyword spelling and success

Correct spelling of the two target keywords was necessary for search success. We examined the number of different spelling attempts made by children and adults as a function of spelling success. As with the above analyses of search success, we collapsed across search task, using a two between subjects (age group and success/failure) analysis of variance. We did not find an effect of age group. We did find an effect of search success, $F(1,67) = 4.99$, $p < .05$. As expected given the difference in number of searches, adults and children who were successful produced fewer spellings ($M = 2.1$, $SD = 1.6$) than those participants who were not successful ($M = 3.1$, $SD = 1.6$).

The different spellings produced by the participants are shown in the Appendix A. Given that adults and children who experienced search success used fewer different spellings of the target words, these participants contributed fewer different spellings than did adults and children who were not successful, particularly for the ptarmigan search. Almost all spellings were phonetically faithful to the targets, generally representing vowels with phonetically similar vowels (e.g., representing the medial vowel in *ptarmigan* with an "a" or "e," representing the final vowel with an "i" or "e"), omitting the doubled consonant in *lemming*, omitting the silent *p* in *ptarmigan*, or omitting the coda /r/ in the first syllable of *ptarmigan*.

Relatively more of the different spellings produced by those participants who achieved success generated a "Did you mean:" response with the correct spelling for the target keyword spellings (60% for spellings produced by participants who achieved search success versus 10% for participants who failed the search task). However, as described above, not all participants followed the "Did you mean:" option, including, for example, the adult who, on seven of nine searches, was provided with "Did you mean: ptarmigan" and never followed the option and ultimately was not successful. On the other hand, following a correct "Did you mean:" option did not necessarily guarantee success, as indicated by the child who, in response to his search for *ptarmagin life cycle* was provided with "Did you mean: ptarmigan life cycle," followed the link, checked out a few of the results, and abandoned that search in favour of *ptarmigen life cycle*.

3.5. Correlations among the measures

We correlated search measures with computer use survey responses and WRAT3 spelling performance to examine whether spelling ability and/or Web use were related to Web search behavior. There were no correlations between spelling skill and reported search skill

with search behavior for adults. For children spelling skill positively predicted search success, $r(36) = 0.32$, $p < .05$; and negatively predicted number of searches performed, $r(36) = -0.55$, $p < .01$, and number of different search strategies, $r(36) = -0.54$, $p < .01$. Children's reported skill at searching the Web negatively predicted selecting the "Did you mean:" suggested spelling, $r(36) = -0.36$, $p < .05$.

4. Discussion

Finding information about a difficult-to-spell topic, such as *ptarmigan*, was more difficult and less successful for all participants than searching for information about an easier-to-spell topic, such as *lemming*. In addition, adults demonstrated different search behaviors than did children when they were unsuccessful at spelling the target keywords, opting more often to change other keywords in the search expression whereas children also tried different spellings of target keywords and followed the "Did you mean:" link suggested by Google. Spelling ability and self-reported search skill was also correlated with success for children: Children who were better spellers and/or reported better skill at searching the Web were more likely to be successful at finding the required information than children who were poorer spellers or who reported being less skilled at searching the Web. However, children and adults who could not eventually spell the target keyword correctly were never successful in their search. In answer to our first research question, these results indicate that correct spelling is important for searching the Web.

An important finding from our study was information on how children and adults changed their search expressions when they were unable to spell the target word correctly. Adults engaged in more adaptive search behaviors than did children when they could not immediately spell the target keyword; that is, their alternative strategies were more likely to be successful than were children's. Adults were less likely than children to try different spellings of the keywords but, instead, changed the search expression, adding or removing keywords, as did a few of the children in the study of Borgman et al. (1995) of online library catalogue searching. Especially for adults, changing the search expression was effective. Children, on the other hand, were more variable in their search behavior and their strategies were not as successful as adults'. A particularly unsuccessful search strategy involved typing in alternative spellings (one child tried 11 different spellings of ptarmigan before the search time limit was reached).

Our findings that children engaged in more variable and less adaptive behavior than adults extends our previous work on children's spelling strategies to a real world task (cf., Kwong & Varnhagen, 2005; Varnhagen, McCallum, & Burstow, 1997). They also add to the growing body of work on the development of children's strategy choices in a wide range of tasks (cf. Siegler, 2006; Siegler & Jenkins, 1989). Both children and adults engaged in a range of search strategies. Children were more variable in the number and type of search strategy changes they made than were adults and their strategies tended to be less effective than were adults' strategies. However, both children and adults who could spell the target keywords were more effective and efficient in searching for and finding the required information. All of these findings provide preliminary support for extending the overlapping waves model of strategy development to understanding Web search. Additional research examining children's changes in search behavior over multiple successful and unsuccessful search tasks in multiple sessions (e.g., using microgenetic methods, Siegler & Crowley, 1991) is necessary. Adopting a theoretical perspective on how children and adults search the Web will help guide research in this relatively new medium as well as support the development of appropriate applications and instruction designed for information search on the Web.

Interestingly, children who initially could not spell the target keywords were more often successful when they followed the "Did you mean:" link to the correct spelling than when they engaged in any other type of search behavior. Given that the "Did you mean:" option often provided an incorrect result for children, using this strategy was not always effective. For example, one child typed the search expression, *life cycle of the lemin*, to which Google responded with "Did you mean: life cycle of the lemon." Although the child followed this link, she quickly discovered her error and recovered, changing the target keyword spelling to *leming*. When she received the response, "Did you mean: life cycle of the lemming," rather than following the link, she typed the spelling to match the suggestion and achieved success. Misspellings of lemming were more likely to return a correct "Did you mean:" spelling; Google more often returned "Did you mean: tarmigan" in the ptarmigan search condition in response to misspellings of the target keyword.

Given that children and adults attend to the spelling suggestions offered by the "Do you mean:" link, our study provides evidence to support the arguments of Bilal (2000, 2001, 2002) and Large et al. (2001) for including spell-checkers in search programs. However, given the quality and relevance of the spelling suggestions obtained in this study, in addition to the varied abilities of the participants to assess this quality and relevance, we argue that the algorithmic frequency-count based spelling program used by Google is not sufficient for use as a spell checker. Search programs need both a true dictionary, with access to keyword definitions, and possibly a phonetic dictionary, with access to keyword pronunciations, to provide useful spelling suggestions. These dictionaries should also include algorithms for common letter deletions and transcription errors. These algorithms would have flagged the missing silent *p* in *ptarmigan*, the missing doubled consonant in *lemming*, and possibly the omitted coda, /r/, in *ptarmigan*.

Supporting our argument, Enchanted Learning, a software company that designs simple interfaces for children, has developed a simple search engine for their Enchanted Learning Web site that includes a true dictionary (http://www.enchantedlearning.com). The dictionary caught many of the misspellings of lemming and ptarmigan we obtained in our study. The Enchanted Learning site included results for the corrected spellings in the list of results as well as pictures for all the results that allow for quickly ruling out incorrect results. As an example, a search for *lamming*, a misspelling we obtained in our study, returned results for *lemming* and for *ramming*. The picture of the rodent provides immediate feedback as to the correct option.

On the other hand, search engines should not be too automatic for effective learning. The multiple spellings and picture results interface of Enchanted Learning may be efficient for presenting results but it does not provide the child with an opportunity to

reflect on his or her misspelling or to select the appropriate spelling. A more appropriate spell-checking feature for learning might include a pull-down menu of possible spellings.

Alternatively — or until a true dictionary is included in search programs — children and adults need to be encouraged to use on-line dictionaries. Google's result page includes links to an on-line dictionary in a bar at the top of the page. The correctly spelled keywords link to the dictionary and the incorrectly spelled words do not. If participants had followed the link to the dictionary (Answers.com) and typed in almost any incorrect spelling (e.g., *tarmigan*, *tarmigon*), they would have been given the correct spelling or at least able to check the dictionary definition to see if they were searching for the correct target.

4.1. Conclusions and implications

In conclusion, our results demonstrate that spelling can influence Web search behavior. Children and adults who could spell the target words were more effective and efficient in finding the required information. Children and adults who could not spell the target words engaged in alternative strategies, ranging from changing spellings of the target and other keywords to following the "Do you mean:" link to bypassing the search program altogether and typing in different URLs. Although children were generally less successful than adults in applying alternative strategies, they were more likely to be successful in following a passive suggestion from the search program whereas adults were more likely to be successful when they actively changed the search expression, sometimes excluding the misspelled target word altogether.

Rather than building in all possible errors into the search database and developing bigram and trigram algorithms to identify possible errors, we concur with Bilal (2000, 2001, 2002) and Large et al. (2001) who argue for a better dictionary. This dictionary should be based on real language and include a phonetic component as opposed to bigram and trigram algorithms. Users should be able to select the desired spelling from a menu of spelling suggestions rather than a single suggestion. Thus, a child typing a misspelling such as *tarmigan* would be able to select among a list of alternative spellings, including *ptarmigan* and *tarbogan*, as suggested by Dictionary.com. Ideally, these selections should also include a brief definition to help the user select the appropriate spelling. When presented with a menu of alternative words, the definitions may help narrow down the alternatives to the correct word.

In addition to implications for search program design, our findings also provide implications for teaching search strategies. Although we hypothesized that children and adults would use external aids such as an on-line dictionary, few participants did so. Most on-line dictionaries that we tried provided the correct spelling for both target keywords in response to almost any misspelling we observed in the study. On-line (and print) dictionaries are very useful external aids yet this research and other research on dictionary use (e.g., Figueredo & Varnhagen, 2006) indicates that dictionaries are generally underused. Given the utility of on-line dictionaries for searching, Web search training and search tip sheets should include a demonstration of using on-line dictionaries for obtaining correct spelling. Some dictionaries (e.g., Dictionary.com, Merriam-Webster OnLine) even provide external links to Web searches for the dictionary item.

The Web is a rich resource for information. Children and adults approach Web search similarly to other problem solving tasks, applying various strategies with varying effectiveness. To support children and adults in their Web search, we need to design useful spell-checking programs and teach searchers to use on-line dictionaries as an effective search strategy.

Appendix A. Spellings produced as a function of age group and search success

	Adult		Child	
Keyword	Success	Failure	Success	Failure
Lemming	leming [a]	–	leming [a] (10) aleming lamming loming lemin lemon	leming [a] leaming leamining leaminig
Ptarmigan	tarmigan [a] (7) tarmagan (2) ptarmagan [a] tarmegan [a] ptaarmagan [a] tarmegin tarmigen tarmengan	tarmagan (7) tarmigan [a] (2) tarmagen (2) tarmagin (2) tarmagon (2) ptarmagaan [a] tarmigin [a] Tarmegin Tarmigon tarmaghan tarmeagin Tarmican tarmongon	tarmigan [a] (3) tarmegan [a] (2) tarmigin [a] (2) tarmagan (2) tarmagen tarmagon tarmigon taremagan taremigan tarmegane tarmign	tarmagin (10) tarmagen (4) tomegan (3) tarmagan (2) ptarmagin [a] tarmigan [a] tarmagn tarmagon tarmegin tarmegin turmigan tarnmigan taremagon tarmageen atomigan atongin atonigan

(*continued on next page*)

Appendix A (*continued*)

	Adult		Child	
Keyword	Success	Failure	Success	Failure
Ptarmigan cont.				taregin tarmagetan tarmangen tarragona tomagain tomagan tomagin tomangan tomegen tomgan tomgin tomoragan tomorgan tonagin tongin trogen tom organ

Note. Numbers in parentheses refer to number of participant (greater than one) producing the spelling.

[a] These spellings generate a "Did you mean:" option containing the correct spelling of the target keyword.

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