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Kinesthetic operant bias in keyboard-based choice behavior

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ABSTRACT
In any type of behavioral research involving a choice element, the researcher must consider the possible methodological challenge of operant bias: a consistent preference for one operant over another. In the first experiment described in this article, originally designed to study the effect of number of prior repetitions of an operant on the frequency with which the operants were subsequently chosen for performance, systematic bias for certain operants over others—strong enough to override the programmed independent variable of the study—was observed. Since the operants in use involved typing non-word sequences of letters on the computer keyboard, it was initially believed that this bias was verbal in origin and related to the specific letter patterns used. The second experiment presented was then designed to remove this source of bias by replacing the letters on the keyboard with symbols. However, more systematic operant bias was observed in Experiment 2 than previously in Experiment 1. Ergonomic analysis of the specific keystrokes making up operants for which bias was observed in Experiment 2 points to three specific and quantifiable kinesthetic biases affecting human typing behavior. These results have implications for any future research involving operant behaviors which require the use of the computer keyboard.

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Operant bias (as opposed to the more commonly referenced stimulus bias) can be defined experimentally as a consistent preference for one operant over another equally available one which cannot be explained by the programmed independent variables. In any type of behavioral research using more than a single operant (which includes all research involving choice), the possibility of operant bias must be considered a methodological issue at the experimental design stage.

In the experimental analysis of operant behavior involving matching, bias is discussed in relation to the generalized matching law (Baum, 1974), defined as a component of the constant which affects how closely the relative rate of different responses matches their relative reinforcement rates. Outside of the matching literature, however, bias is rarely referenced by behavior analysts, and has not been studied in depth as a topic in its own right.

In a previous article, we presented a series of systematic, quantifiable operant biases observed in human participants while conducting research that involved choices, using a type of operant which consisted of lines drawn on a computer graphics tablet (Jones &

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Mechner, 2013). Since operant bias is, by definition, not under the experimenter's control, it is difficult to say with certainty which of the multiple possible causes of operant bias are at work in any specific experimental results. However, some of the biases observed in this previous research were clearly related to the kinesthetic aspects of the operant behavior in question (defined as the motions required to complete it), while others seemed more related to the perceptual aspects of the operant (the sensory input involved in performing the task).

The current experiments were performed as part of a series of studies on the effect of prior repetition of groups of operants on the relative frequency with which they are subsequently chosen for performance (Jones & Mechner, 2007; Mechner & Jones, 2015). Previous experiments in the series, which consistently found a preference for operants which had been repeated more often, used multiple complex operants, each consisting of a long string of letter keypresses typed on a modified version of a standard computer keyboard. Such an operant is called a revealed operant because its structure reveals more than one measurable dimension (Mechner, 1994). The revealed operant unit consists of a sequence of actions whose beginning and end is marked by distinct behavioral events. It was used in these studies because it allows for more elaborate analysis.

The two experiments described in the present article were initially designed to study the effect of the frequencies with which operants had previously been repeated, and the ratios of those frequencies, on the relative frequency with which those operants were subsequently chosen for performance. Each repetition frequency and ratio was assigned to three pairs of alternative operants that were presented to the participants in simple forced choice situations. The secondary purpose of this research was to determine whether a large number of novel letter keypress patterns would function as neutral and equivalent operants (i.e. not subject to operant bias) for future studies of this type.

We found systematic (i.e. across participants) operant bias for a number of the operants used in Experiment 1. Methodological changes designed to decrease this bias in Experiment 2, by removing the letters of the alphabet as potential sources of bias, were completely unsuccessful, leading to the present analysis of the operant bias observed. Quantitative analysis of the data revealed the existence of major kinesthetic sources for operant bias related to the ergonomic aspects of using the computer keyboard.

Experiment 1

Method

Participants

The participants were 13 adults over the age of 18, recruited through flyers posted on local college campuses. Participants were told they could earn up to a total of $300 for completing 14 experimental sessions, each approximately an hour in length, taking place at the same time of day on 14 consecutive weekdays.

They were paid a flat fee of $5 per session for their participation; the remainder of their compensation was a bonus paid as a lump sum after the completion of the final session, the exact amount of which depended on their performance during the multiple

"test" periods scheduled throughout the study. Participants were informed that they were free to withdraw from the experiment at any time and keep the $5 fee for all sessions they had attended, but would receive the final bonus payment only if they completed all 14 sessions. Out of 17 participants, 4 withdrew during the course of the experiment.

Participants agreed to keep their sleeping and eating habits and their caffeine consumption consistent during the course of the study. They received an explanation of all requirements of the study in writing at the beginning of the first session, which they signed to indicate that they understood them. After they had completed the last session of the experiment, the experimenter debriefed them regarding the purpose of the study.

Setting

The participants sat at desk chairs at four computer workstations arranged against the walls of a 9' by 12' room, with their backs to the center of the room. Each workstation was separated visually from the others by screens.

Apparatus

The apparatus for this experiment consisted of four Dell 486 desktop computers. Each had a 14-inch CRT monitor placed at slightly below the participant's eye level, and a keyboard at a comfortable height for typing. A custom-made particleboard mask, shown in Figure 1, covered all keys on the keyboard not in use during this experiment. Only 12 letter keys (T, Y, U, I, G, H, J, K, V, B, N, and M) were accessible, along with the space bar, enter key, number keypad and a few function keys. This group of letter keys was chosen so as to fall in between the normal "home" position of the hands (the keys above which typing students are taught to hold their left and right hands); the keyboard mask thus made it harder for the participants to type as they usually did, disrupting their practiced typing routines.

Figure 1. Picture of the keyboard used in Experiment 1, showing the subset of 12 letter keys in use during the experiment.

Customized software, written in the Euphoria programming language, controlled the experimental input and output, providing the appropriate visual and auditory stimuli and tracking every keystroke performed.

Design

Both experiments presented in this article used an operant design consisting of a sequence of eight keystrokes, the general form of which was as follows: a press of the space bar, followed by a string of six letter keypresses from the 12 available on the keyboard, followed by the enter key. The specific six letters which defined each individual operant were mandated by the experimenter and were non-word letter patterns. During Experiment 1, participants performed 56 unique operants, each with a different six-letter pattern, which they learned two at a time, in 28 operant pairs. Each of the two operants in each pair was repeated a specific number of times, with one of the two (hereafter referred to as the more-practiced operant) always repeated more often than the other (referred to as the less-practiced operant). At no time during the experiment were the letters typed by the participants displayed on the monitor.

The required operant alternated back and forth between the two in the pair currently being performed, with each one performed in a "block" of between 10 and 25 operant repetitions before the software required the other one again. The software displayed the 6-letter pattern to be typed on the computer monitor as a prompt at the beginning of each block. These blocks varied in length on a randomized schedule so as to be unpredictable to the participants and make it more difficult for them to keep count of the number of repetitions. Only correctly typed operants were counted toward the number required to complete an operant block. A feedback stimulus (i.e. one produced by the organism's own behavior)—in the form of a large (3 by 3 inch), bright green square which flashed on the monitor for .5 seconds after the enter key was pressed—was presented to the participants after every correctly typed operant to ensure that all operants were performed correctly for the number of repetitions that were counted during the repetition phase of the experiment.

After the participants completed the programmed number of repetitions for both operants in a pair, they were prompted to choose between the two by taking a brief "test." At the beginning of each test block the monitor displayed the message: "Please begin the test when you are ready. You will be shown two patterns. Type whichever one you like." Participants then chose which of the most recent pair of operants to perform. The display alternated which operant was listed first, to cancel out the possible effect of participants simply typing the first operant listed.

For each operant that was typed correctly during testing, participants received 25 cents and at the same time were presented with a beep sound of 440 Hz for .125 seconds, and screen presentation of the words, "You just earned 25 cents. Ring it up." Participants then performed a "consumatory" response (defined behaviorally as the response occasioned by a reinforcer presentation) which consisted of typing 25 on the number keypad and then pressing enter, at which point the amount was added to a running total of their earnings during the current session, displayed in the top left corner of the screen. This procedure was used in order to ensure participants' attention to the reinforcers. If they made a mistake (mis-typed the operant, or typed another operant which was not one of the two currently active ones), or if they paused for too

long between keystrokes at any time during the test, they lost 15 cents. When this happened, the computer emitted a low-pitched sound of 110 Hz for .125 seconds and that amount was automatically deducted from their total.

The time limit for pausing during test blocks was programmed to match each individual participant's average speed and was constantly adjusted throughout the test blocks, in order to be equally stressful for all participants. The time limit between keystrokes within an operant was initially set at 1.5 seconds, while the time limit for the pause between consecutive operants was initially set at 3.5 seconds. After the first three test operants chosen, the limit adjusted automatically to 1.2 times the average of those times over the last three operants typed by that participant.

Five test blocks were presented for each operant pair learned, each one limited to 10 operant attempts apiece (whether correctly typed or not), and were scheduled so as to alternate with the first four learning blocks for the next operant pair. Breaking up the 50-operant test period into five smaller blocks was done so as to allow participants to change which of the two operants in the pair they chose for performance more easily during testing, if desired. (Otherwise, momentum during the fast-paced test could result in the participants merely repeating the first operant chosen for the entire test period.)

The total number of blocks per session was chosen so that each session would take about an hour or less for participants working at a typical speed (based on previous experiments with similar operants). This was done so that participants would not become bored or fatigued with overly long experimental sessions. The first session consisted of a total of 500 required operant repetitions, the second 600, the third 700, the fourth 800, and every session after that, 900. For each participant, the session ended when that session's programmed number of operant repetitions had been completed, regardless of how long it took.

Three different repetition ratios (2:3, 2:4, and 2:5) were used in this experiment, at three different absolute repetition values (low, medium, and high), for a total of nine different repetition ratios tested, as seen in Table 1. No "pretesting" procedures (often used to determine baseline preference for the different operants used in an experiment) were incorporated into the experiment, as due to the very small number of repetitions required for some operants, any additional exposure to them might have impacted the effect of the relative number of repetitions required.

Table 1. Repetition ratios and absolute levels for repetitions required in Experiment 1.

Absolute repetition values	Relative repetition ratios	Actual number of repetitions per operant pair
Low	2:3	50:75
	2:4	50:100
	2:5	50:125
Medium	2:3	100:150
	2:4	100:200
	2:5	100:250
High	2:3	200:300
	2:4	200:400
	2:5	200:500

The 13 participants in Experiment 1 were divided into two groups, Group A and Group B, with 6 participants in Group A and 7 in Group B. Both groups learned, performed, and were tested on the same 56 operants (28 choice pairs), but Group B was presented with the 28 operant pairs in a different randomized order than Group A. Also, each operant pair was required for a different number of repetitions for Group B than for Group A. This was done to control for possible order effects in the study.

Three different pairs of operants were assigned to each repetition ratio. Note that the first and last pair of operants (which are the same: YUGJNH and IMHVYU) were "throwaway" operants, used for the first and last test in the study in order to prevent the behavioral distinctiveness of those anchor points (i.e. the natural reference points at the beginning and end of any behavioral sequence) from affecting the experimental results. Results from test periods 1 and 29 were thus not counted in the data.

Table 2 shows the actual letters making up each operant, as well the order in which it was learned and its relative repetition ratio and absolute repetition level for

Table 2. Operants used in Experiment 1.

Less-practiced operant	More-practiced operant	Participants: Group A				Participants: Group B			
		Order	Repetitions	Ratio	Value	Order	Repetitions	Ratio	Value
YUGJNH	IMHVYU	1/29	60:60	N/A	N/A	1/29	60:60	N/A	N/A
TIHMJY	MVJGUI	4	50:75	2:3	Low	3	100:250	2:5	Med
MVGJYT	JHYIGU	15	50:75			14	200:400	2:4	High
KTUGNI	NBIGYN	26	50:75			25	100:200	2:4	Med
ITKVHM	BJMNJU	5	100:150	2:3	Med	4	50:75	2:3	Low
KNVBUI	UYJBHM	13	100:150			12	50:125	2:5	Low
JKGYUJ	TKUHIB	28	100:150			27	200:500	2:5	High
BHJMHK	GUKYJI	7	200:300	2:3	High	6	50:125	2:5	Low
HNKGHU	YTKBJI	11	200:300			10	50:100	2:4	Low
TYNVGY	MHYUIK	22	200:300			21	100:250	2:5	Med
JYTHUK	VHMGJK	10	50:100	2:4	Low	9	100:200	2:4	Med
BUIGHK	MBKUYJ	18	50:100			17	100:200	2:4	Med
VGJBYU	NGYHVJ	20	50:100			19	200:500	2:5	High
NKUGYM	GYJTHU	9	100:200	2:4	Med	8	200:500	2:5	High
YUKVHJ	TMYIBY	17	100:200			16	100:250	2:5	Med
UIBTYJ	JVBMHG	25	100:200			24	50:125	2:5	Low
GTMKJT	HKTBVU	2	200:400	2:4	High	28	100:150	2:3	Med
NYTKUH	YJIBNM	14	200:400			13	100:150	2:3	Med
YBHMBU	UHBNKY	23	200:400			22	200:300	2:3	High
NYGNIB	MUBYNI	6	50:125	2:5	Low	5	100:150	2:3	Med
BYKHNJ	VTNGBJ	12	50:125			11	200:300	2:3	High
HJIHMN	BVKHIY	24	50:125			23	200:400	2:4	High
JMGNKH	KJYIGJ	3	100:250	2:5	Med	2	200:400	2:4	High
UGKJIB	KHBNJG	16	100:250			15	50:75	2:3	Low
IBJTHK	GBJMHT	21	100:250			20	50:100	2:4	Low
VNKJTI	HUBTHI	8	200:500	2:5	High	7	200:300	2:3	High
KGNJHT	IYGMHV	19	200:500			18	50:100	2:4	Low
HUMTUI	VYNKUB	27	200:500			26	50:75	2:3	Low

each group of participants. The shaded blocks indicate operant pairs for which either the underlying relative repetition ratio, or the absolute repetition level, happens to be the same for both Group A and Group B (due to the difficulty of balancing all the different training variables across the many conditions); for all other operant pairs (the vast majority), both of those training variables are different for the two groups.

Procedure

At the beginning of the first session, each participant logged in to the computer and went through a demo of the software used, including both learning blocks and test blocks. Once the login process was completed, the computer displayed the six-letter pattern for the first operant to be learned in the middle of the screen ("YUGJNH"—one of the throwaway operants, for which the later test data were not counted), followed by the words "Hit the F1 key to continue." The experimenter then instructed the participants on how to perform each operant, and watched the participants perform the demo, answering any questions asked. The first time participants earned 25 cents, the experimenter instructed them on the procedure required to perform the consumatory response.

After the software demo was completed, the experimenter set up the first session program on each workstation and observed the participants logging in using the procedure already taught. At the end of each day's required number of operant repetitions, the computer displayed the message "You have completed today's session. Please call the experimenter to record your total." The experimenter then came into the room to record the total amount of money earned by the participant and sign the participant out for the day. On days 2 through 14 of the study, participants signed in when arriving on the premises and then started their sessions themselves.

Results

The stacked columns in Figure 2 show the percentage (not average) of all operants chosen by all participants (both Group A and Group B) during all test sessions from the less-practiced vs. the more-practiced alternatives, with the proportion chosen from the more-practiced alternative at the top of each column, and that from the less-practiced alternative on the bottom. All columns sum to 100%. Each column combines the frequency-of-performance results for the three less-practiced and the three more-practiced operants at each absolute repetition value (shown on the *x*-axis); they are clustered in three separate panels, one for each relative repetition ratio (labeled at top).

There is an overall effect of repetition frequency on performance frequency—i.e. operants that were practiced more often are generally more likely to be chosen for performance during testing than operants practiced less often. However, a large amount of variability among participants was observed (for the complete individual choice data, which is too complex to be displayed visually, please see Tables 3 and 4—Table 3 contains the data for Group A participants and Table 4 the data for Group B participants, clustered by the differing repetition values for each group of operants for those participants). As the figure and tables show, analysis

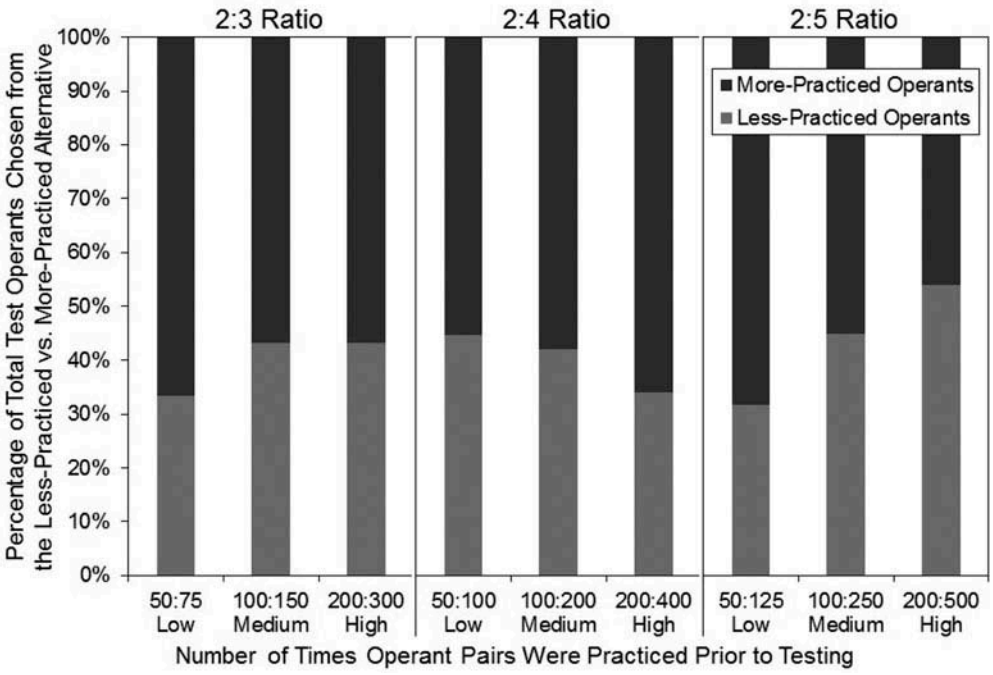

Figure 2. Choice results during testing for Experiment 1, showing the proportion of the total number of operants chosen during testing by all subjects from the less-practiced operants vs. the more-practiced alternatives in each operant pair. Results are categorized by both the relative ratio of repetitions prior to testing (grouped into three separate panels left to right, labeled at top) and the absolute value of prior repetitions (along the *x*-axis).

of the data found no systematic or quantifiable effects of the relative ratio of repetitions or the absolute value of repetitions on the degree of preference for the more-practiced operants.

Furthermore, comparative analysis of the data from Group A participants vs. the data from Group B participants showed no effect of the order in which the operant pairs were learned. There were differences in performance between Group A and Group B participants: overall, preference for the less-practiced operant alternatives was 6.31% higher in Group B than in Group A, and certain individual operants were chosen for performance far more often by one group than by the other. Given the frequent large differences in operant choice between individual participants observed in this experiment as well as later in Experiment 2, however, these differences between groups appear to be well within the overall range of variability observed in this type of research.

Although there were no systematic effects of any of the programmed training variables on the relative frequency of later performance, there were effects of the specific six-letter patterns used to make up the operant pairs. In many cases, it is evident that whether the more-practiced operant at a given repetition ratio was performed more frequently depended more on which two specific six-letter patterns

Table 3. Complete individual choice data for Group A participants, Experiment 1.

Group A participant #	Less-practiced operant	More-practiced operant	Less-practiced operant	More-practiced operant	Less-practiced operant	More-practiced operant
2:3 ratio, low values	TIHMJY 50 reps	MVJGUI 75 reps	MVGJYT 50 reps	JHYIGU 75 reps	KTUGNI 50 reps	NBIGYN 75 reps
5401	0	49	10	39	0	49
5402	38	10	0	48	0	50
5403	0	50	0	50	0	50
5404	0	50	0	50	0	50
5405	0	48	50	0	50	0
5407	10	39	0	48	48	0
Total	48	246	60	235	98	199
Grand total for all 3 operant pairs in this category:					206	680
2:3 ratio, med values	ITKVHM 100 reps	BJMNJU 150 reps	KNVBUI 100 reps	UYJBHM 150 reps	JKGYUJ 100 reps	TKUHIB 150 reps
5401	0	50	0	50	49	0
5402	0	49	0	49	49	0
5403	49	0	49	0	0	50
5404	0	50	0	50	50	0
5405	0	50	50	0	50	0
5407	0	49	47	0	0	49
Total	49	248	146	149	198	99
Grand total for all 3 operant pairs in this category:					393	496
2:3 ratio, high values	BHJMHK 200 reps	GUKYJI 300 reps	HNKGHU 200 reps	YTKBJI 300 reps	TYNVGY 200 reps	MHYUIK 300 reps
5401	0	50	0	50	50	0
5402	19	28	49	0	49	0
5403	0	49	0	50	40	10
5404	10	39	50	0	50	0
5405	10	40	50	0	50	0
5407	10	38	0	48	0	48
Total	49	244	149	148	239	58
Grand total for all 3 operant pairs in this category:					437	450
2:4 ratio, low values	JYTHUK 50 reps	VHMGJK 100 reps	BUIGHK 50 reps	MBKUYJ 100 reps	VGJBYU 50 reps	NGYHVJ 100 reps
5401	0	49	49	0	10	38
5402	50	0	0	48	0	50
5403	40	10	49	0	50	0
5404	0	49	0	50	0	46
5405	0	49	50	0	50	0
5407	50	0	0	47	0	38
Total	140	157	148	145	110	172
Grand total for all 3 operant pairs in this category:					398	474
2:4 ratio, med values	NKUGYM 100 reps	GYJTHU 200 reps	YUKVHJ 100 reps	TMYIBY 200 reps	UIBTYJ 100 reps	JVBMHG 200 reps
5401	0	49	0	50	0	50
5402	0	50	49	0	0	49
5403	39	9	50	0	0	50
5404	0	50	50	0	0	50
5405	0	50	59	0	0	50
5407	50	0	0	50	0	47
Total	89	208	208	100	0	296
Grand total for all 3 operant pairs in this category:					297	604
2:4 ratio, high values	GTMKJT 200 reps	HKTBVU 400 reps	NYTKUH 200 reps	YJIBNM 400 reps	YBHMBU 200 reps	UHBNKY 400 reps
5401	49	0	0	50	0	50
5402	49	0	0	49	0	49
5403	0	47	0	50	0	50
5404	0	48	0	50	50	0
5405	0	47	0	48	0	50
5407	47	0	38	9	0	50
Total	145	142	38	256	50	249
Grand total for all 3 operant pairs in this category:					233	647

(*Continued*)

Table 3. (Continued).

Group A participant #	Less-practiced operant	More-practiced operant	Less-practiced operant	More-practiced operant	Less-practiced operant	More-practiced operant
2:5 ratio, low values	NYGNIB 50 reps	MUBYNI 125 reps	BYKHNJ 50 reps	VTNGBJ 125 reps	HJIHMN 50 reps	BVKHIY 125 reps
5401	0	50	40	10	40	9
5402	0	49	47	0	0	50
5403	0	43	0	50	50	0
5404	0	47	30	20	0	50
5405	49	0	0	50	0	49
5407	0	46	49	0	10	39
Total	49	235	166	130	100	197
Grand total for all 3 operant pairs in this category:					315	562
2:5 ratio, med values	JMGNKH 100 reps	KJYIGJ 250 reps	UGKJIB 100 reps	KHBNJG 250 reps	IBJTHK 100 reps	GBJMHT 250 reps
5401	40	9	49	0	0	50
5402	0	45	0	49	40	10
5403	38	10	50	0	0	50
5404	0	46	0	50	0	50
5405	50	0	0	50	0	50
5407	18	19	0	47	0	50
Total	146	129	99	196	40	260
Grand total for all 3 operant pairs in this category:					285	585
2:5 ratio, high values	VNKJTI 200 reps	HUBTHI 500 reps	KGNJHT 200 reps	IYGMHV 500 reps	HUMTUI 200 reps	VYNKUB 500 reps
5401	0	50	50	0	50	0
5402	0	50	50	0	0	48
5403	0	49	0	50	0	50
5404	0	50	49	0	50	0
5405	0	50	50	0	50	0
5407	0	49	49	0	46	0
Total	0	298	248	50	196	98
Grand total for all 3 operant pairs in this category:					444	446

were tested against each other than on the number of times either of them had been required before that test.

Figure 3 shows the total (aggregated across Group A and Group B) results during testing for all 27 individual operant pairs learned in Experiment 1. As none of the training variables had any differential effect on preference within the individual operant pairs, they are arranged in order of preference for the less-practiced alternative for ease of visual reference. The figure shows that degree of preference for the more-practiced alternative varies widely depending on the specific operant pair in use. In particular, for the 12 specific operant pairs for which data are displayed to the right of the dotted line, more than 50% of the operants chosen by the participants for performance during testing came from the less-practiced alternative, regardless of how many times it or the more-practiced alternative in that pair had been repeated. This can be taken as a robust experimental definition of operant bias: one (previously presumed to be neutral) operant being preferred over another despite the fact that such preference goes directly against the experiment's programmed independent variable. Operant bias for a less-repeated alternative thus represents a level beyond indifference between two equivalent operant behaviors.

Based on this definition of operant bias, the 12 less-practiced operants for which bias occurred in Experiment 1 were selected for display in Figure 4, which compares the

Table 4. Complete individual choice data for Group B participants, Experiment 1.

Group B participant #	Less-practiced operant	More-practiced operant	Less-practiced operant	More-practiced operant	Less-practiced operant	More-practiced operant
2:3 ratio, low values	ITKVHM 50 reps	BJMNJU 75 reps	UGKJIB 50 reps	KHBNJG 75 reps	HUMTUI 50 reps	VYNKUB 75 reps
5409	0	49	35	7	50	0
5410	0	43	47	0	49	0
5412	49	0	50	0	0	50
5414	0	50	0	50	50	0
5415	0	45	0	47	0	48
5416	0	47	0	49	49	0
5417	0	50	0	50	50	0
Total	49	284	132	203	248	98
Grand total for all 3 operant pairs in this category:					429	585
2:3 ratio, med values	GTMKJT 100 reps	HKTBVU 150 reps	NYGNIB 100 reps	MUBYNI 150 reps	NYTKUH 100 reps	YJIBNM 150 reps
5409	0	46	0	47	0	48
5410	0	48	47	0	49	0
5412	0	50	0	49	0	50
5414	49	0	0	50	40	9
5415	50	0	47	0	0	47
5416	49	0	50	0	0	49
5417	50	0	0	50	0	50
Total	198	144	144	196	89	253
Grand total for all 3 operant pairs in this category:					431	593
2:3 ratio, high values	VNKJTI 200 reps	HUBTHI 300 reps	BYKHNJ 200 reps	VTNGBJ 300 reps	YBHMBU 200 reps	UHBNKY 300 reps
5409	0	50	47	0	0	50
5410	0	49	49	0	49	0
5412	50	0	50	0	0	50
5414	0	48	50	0	0	50
5415	0	46	43	0	0	50
5416	0	50	0	50	0	49
5417	0	48	50	0	0	50
Total	50	291	289	50	49	299
Grand total for all 3 operant pairs in this category:					398	640
2:4 ratio, low values	HNKGHU 50 reps	YTKBJI 100 reps	KGNJHT 50 reps	IYGMHV 100 reps	IBJTHK 50 reps	GBJMHT 100 reps
5409	0	45	40	10	0	50
5410	0	50	49	0	0	49
5412	0	50	0	50	50	0
5414	47	0	0	49	50	0
5415	37	7	46	0	0	47
5416	30	20	0	50	0	48
5417	50	0	46	0	0	49
Total	164	172	181	159	100	243
Grand total for all 3 operant pairs in this category:					445	574
2:4 ratio, med values	JYTHUK 100 reps	VHMGJK 200 reps	BUIGHK 100 reps	MBKUYJ 200 reps	KTUGNI 100 reps	NBIGYN 200 reps
5409	0	49	50	0	0	50
5410	0	48	29	20	0	50
5412	0	50	50	0	0	50
5414	50	0	50	0	0	50
5415	41	0	47	0	0	50
5416	49	0	50	0	0	50
5417	49	0	50	0	0	50
Total	189	147	326	20	0	350
Grand total for all 3 operant pairs in this category:					515	517
2:4 ratio, high values	JMGNKH 200 reps	KJYIGJ 400 reps	MVGJYT 200 reps	JHYIGU 400 reps	HJIHMN 200 reps	BVKHIY 400 reps
5409	0	48	50	0	0	50
5410	30	18	0	50	48	0

(*Continued*)

Table 4. (Continued).

Group B participant #	Less-practiced operant	More-practiced operant	Less-practiced operant	More-practiced operant	Less-practiced operant	More-practiced operant
5412	42	0	0	50	0	50
5414	50	0	50	0	0	50
5415	0	50	48	0	0	50
5416	49	0	0	45	0	50
5417	50	0	0	50	0	49
Total	221	116	148	195	48	299
Grand total for all 3 operant pairs in this category:					417	610
2:5 ratio, low values	BHJMHK 50 reps	GUKYJI 125 reps	KNVBUI 50 reps	UYJBHM 125 reps	UIBTYJ 50 reps	JVBMHG 125 reps
5409	0	45	0	49	50	0
5410	0	49	0	49	0	50
5412	0	50	50	0	0	49
5414	0	50	39	9	50	0
5415	0	46	0	44	0	48
5416	0	50	49	0	0	50
5417	0	50	50	0	0	50
Total	0	340	188	151	100	247
Grand total for all 3 operant pairs in this category:					288	738
2:5 ratio, med values	TIHMJY 100 reps	MVJGUI 250 reps	YUKVHJ 100 reps	TMYIBY 250 reps	TYNVGY 100 reps	MHYUIK 250 reps
5409	0	44	50	0	50	0
5410	0	47	47	0	49	0
5412	0	48	50	0	0	50
5414	49	0	50	0	0	50
5415	44	0	49	0	0	48
5416	27	18	48	0	0	50
5417	0	50	49	0	0	50
Total	120	207	343	0	99	248
Grand total for all 3 operant pairs in this category:					562	455
2:5 ratio, high values	NKUGYM 200 reps	GYJTHU 500 reps	VGJBYU 200 reps	NGYHVJ 500 reps	JKGYUJ 200 reps	TKUHIB 500 reps
5409	0	49	50	0	50	0
5410	0	49	50	0	47	0
5412	50	0	49	0	0	50
5414	0	50	50	0	50	0
5415	0	49	50	0	49	0
5416	0	50	0	50	0	49
5417	0	50	50	0	50	0
Total	50	297	299	50	246	99
Grand total for all 3 operant pairs in this category:					595	446

degree of operant bias measured for these 12 specific operants by participants in Group A to that for Group B. For 8 out of the 12 less-practiced operants for which bias was observed, operant bias was observed for both Group A and Group B participants despite the fact that the two groups had learned these specific operants in a different order, and repeated them a different number of times. As mentioned, there are significant differences between the groups—in particular, for 10 out of the 12 operants bias is greater in Group B participants than in Group A—but the differences between groups are not larger than those measured between individuals within the same group, and thus neither group can be said to be more representative of the overall bias measured.

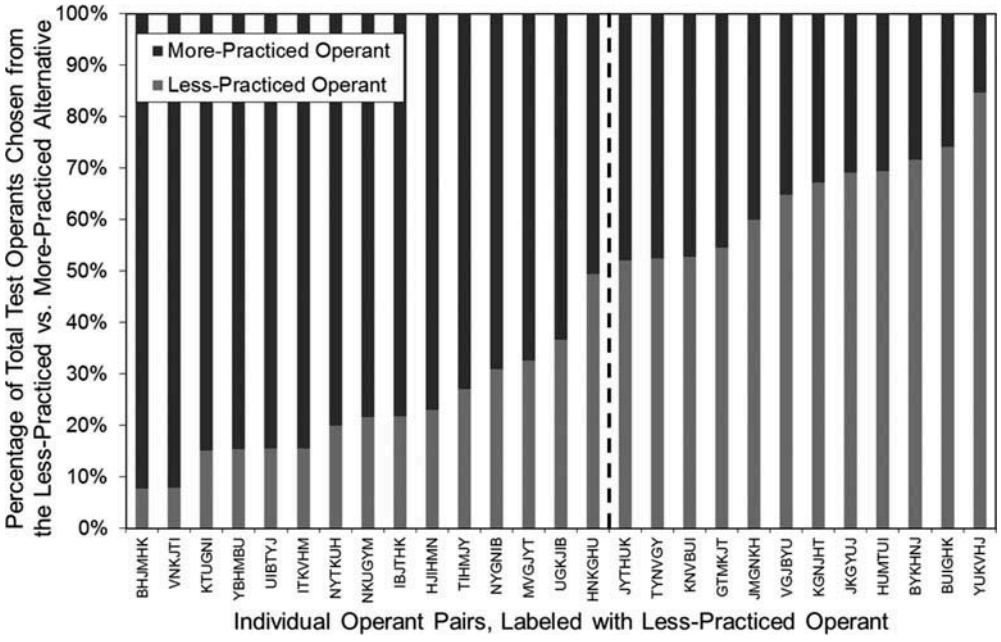

Figure 3. Choice results during testing for individual operant pairs in Experiment 1, arranged in order of least to most preference for the less-practiced operant in the pair. The 12 operant pairs to the right of the dotted line are those for which more than 50% of the total operants performed during testing were from the less-practiced alternative, thus demonstrating bias for those operants.

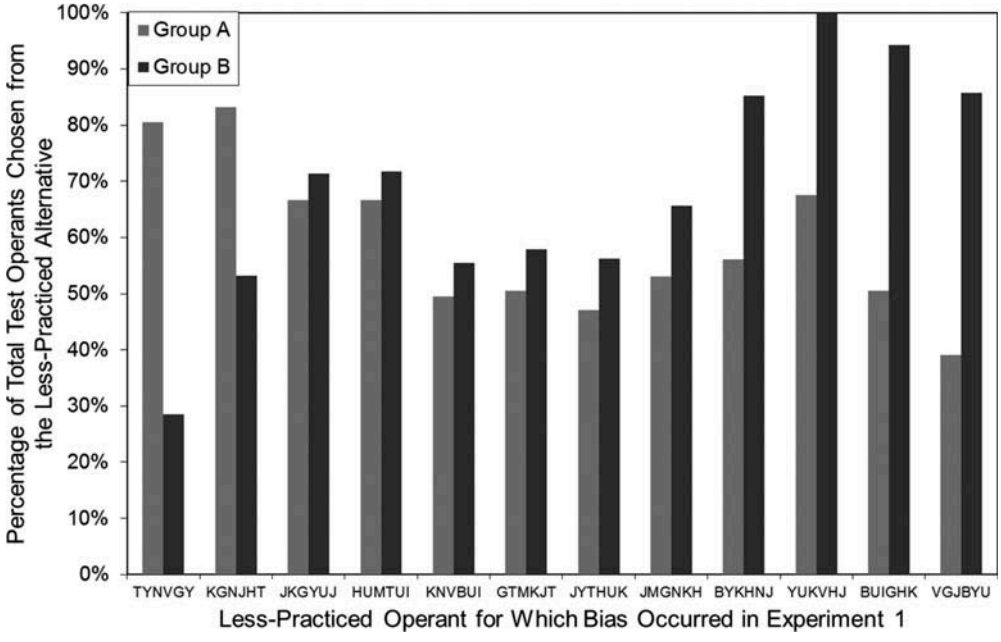

Figure 4. Degree of operant bias measured for the 12 less-practiced operants in Experiment 1 that were chosen more than 50% of the time during testing. The results for the two different groups of participants, A and B, are shown side by side, arranged in order of amount of difference between the groups.

Discussion

This experiment did indeed produce data on repetition effects as planned. Overall, we see that operants which are repeated more often are then more likely to be chosen for performance over less-repeated alternatives under "test" conditions. These results are in line with our prior experiments on the effects of repetition as the independent variable (Jones & Mechner, 2007; Mechner & Jones, 2015).

However, the current findings are very far from consistent, and the large amount of variation in the test results observed among the three specific operant pairs programmed at each repetition ratio, as well as the fact that the relative frequency of occurrence of the operant pairs during testing (even those that show a repetition effect) does not necessarily match the relative rate of prior reinforcement, indicates that the dependent variable is not well controlled by the independent variable in this experiment. There is systematic (not just idiosyncratic) operant bias for 12 of the 27 less-practiced operants, a significant minority of those available in the study. Clearly, a large number of our participants prefer some operants to others based on the specific letter patterns being typed on the keyboard, an aspect of the operant which is supposed to be neutral in its effects.

The robustness of the operant bias observed is evident. The fact that human participants demonstrate preferences for some non-word patterns of letters over others is well-known in experimental psychology. Ebbinghaus (1885/1964) himself noted that the "nonsense syllables" he used in his memory experiments varied widely in terms of how easily his participants learned them. After Ebbinghaus, a whole literature developed within experimental psychology on the "association value" or "meaningfulness" of nonsense syllables, or their degree of resemblance to English words, and thus on their ranking and potential for bias (Jenkins, 1985).

Given this well-known tendency of humans to favor certain groupings of letters over others, we decided to repeat this experiment in a format that avoided the use of letters of the alphabet entirely, while keeping all other aspects of the experimental design as similar as possible. We would then compare the degree of operant bias measured with that observed in Experiment 1.

Experiment 2

Method

Participants

The participants were six adults, recruited in the same way as in Experiment 1. Participants were told they could earn up to a total of $350 for completing 14 experimental sessions, each approximately an hour in length, taking place at the same time of day on 14 consecutive weekdays. (The projected earnings total was revised upward to reflect our experience from Experiment 1.) As in Experiment 1, they were paid $5 in cash at the end of each session they attended, with the remainder of their compensation depending on their performance during the test periods, and paid as a bonus at the end of the study. They were also again informed that they were free to withdraw from the experiment at any time. Three out of the 9 original participants withdrew during the experiment. All participants signed the same agreements and were debriefed in the same manner as those in Experiment 1.

Setting and apparatus

The setting and apparatus for Experiment 2 were also identical to that used in Experiment 1, with the exception that the 12 letter keys accessible on the modified keyboard were covered with stickers printed with symbols, as shown in Figure 5. Therefore, although the specific keystrokes typed in order to complete each operant remained exactly the same as in Experiment 1, the letters themselves were no longer present and each operant now consisted of a sequence of six symbols typed using the covered letter keys on the keyboard, preceded by the space bar and followed by the enter key. Table 5 shows each symbol more clearly next to the letter it replaced.

Design and procedure

The design and procedure of Experiment 2 were identical to that used for Group A in Experiment 1 except for very slight procedural changes. At the beginning of the software demo which participants performed in the first session, the computer monitor displayed all 12 symbols on the screen (shown in Figure 6) so that participants could see them and match them visually with the stickers on the keyboard.

Throughout the experiment, then, when prompting participants to perform a given operant, or choose between the two most-recently performed ones, instead of displaying

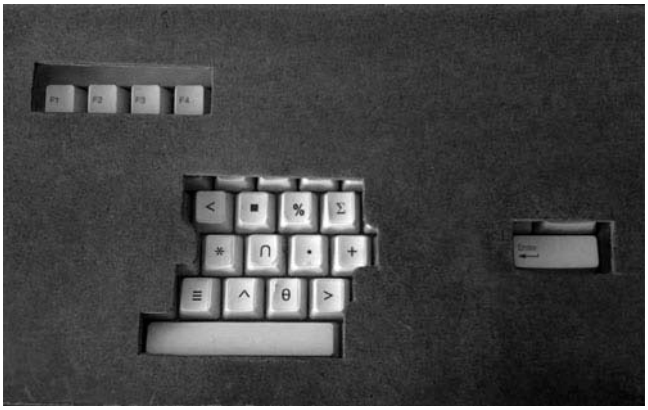

Figure 5. Close-up of the keyboard used in Experiment 2, with the 12 letters on the letter keys replaced by symbols.

Table 5. Symbols which replaced letters in Experiment 2 operants.

Letter used in Experiment 1	Converted to…	Symbol used in Experiment 2
T	→	<
Y	→	■
U	→	%
I	→	Σ
G	→	*
H	→	∩
J	→	•
K	→	+
V	→	≡
B	→	^
N	→	θ
M	→	>

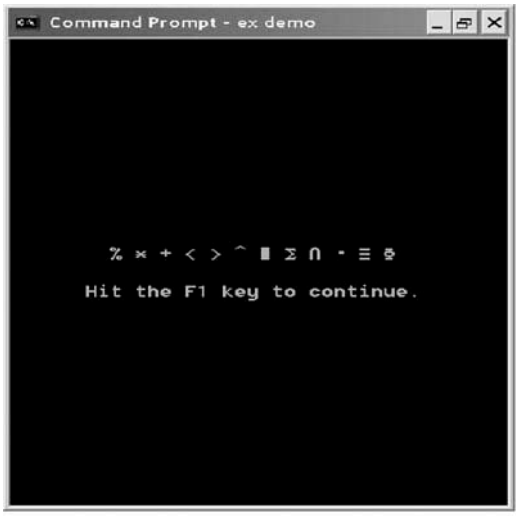

Figure 6. Screengrab of instructions displayed at the beginning of the software demo for Experiment 2, showing the 12 symbols which replaced letters to designate the six middle keystrokes of each operant.

the letters associated with the six letter keys making up each operant, the monitor displayed the six symbols in the appropriate sequence instead.

Additionally, as the participants in Experiment 1 had performed much better than expected during test periods (earning an average of $100 more than the $300 total compensation promised when they were recruited), the length of each test period was decreased slightly from 50 to 40 operant attempts (five blocks of eight operant attempts per period). This modification helped to bring participants' earnings more in line with expectations and ensured that they were motivated to do well on each and every test.

Results

Figure 7 shows the total percentage of all operants chosen by the participants for performance during all test periods from the less-practiced (bottom) vs. the more-practiced (top) alternatives. As in Figure 2, each of the nine columns combines the results for the three less-practiced and more-practiced operants at each absolute repetition value, and the three separate panels group the data for the three repetition ratios. (The percentage data for both this figure and Figure 2 are compared in Table 7)

There is still some general effect of number of repetitions on subsequent performance frequency, but overall, the repetition effect is weaker than that observed in Experiment 1. Again, there were large differences among the individual participants; complete individual data for Experiment 2 are shown in Table 6, with operant pairs grouped by number of repetitions. As in Experiment 1, there was no effect of the various training variables on test performance; again it is clear that in many cases the individual operants themselves are systematically affecting which operants are chosen for performance. (Please note that individual operants in Table 6, as well as the following Figures 8 and 9, are still displayed using letters rather than symbols; this is done only for discussion purposes and to allow

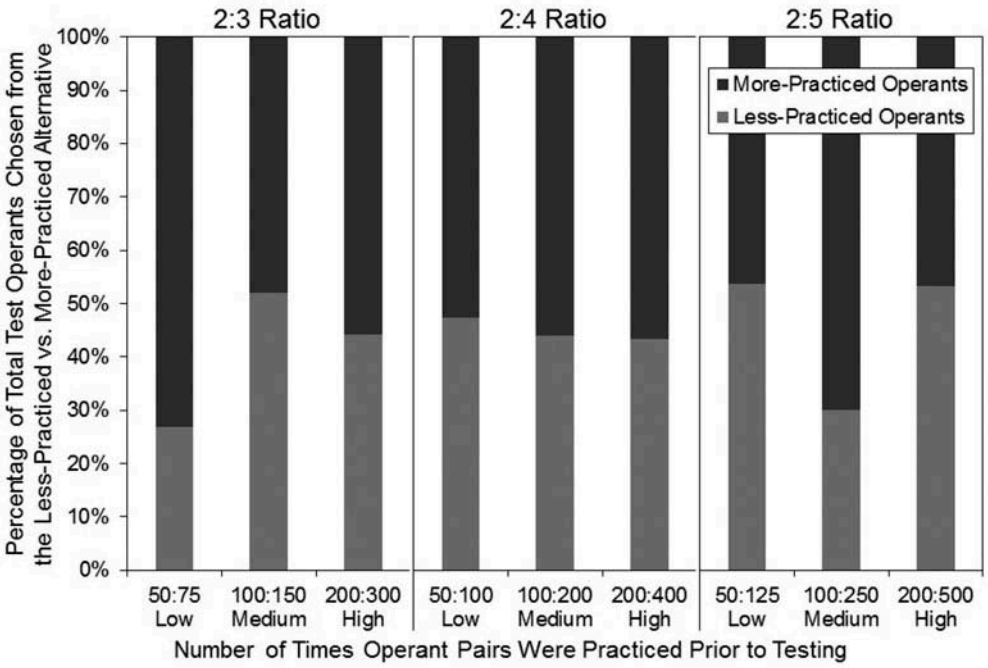

Figure 7. Choice results during testing for Experiment 2, showing the proportion of the total number of operants chosen during testing by all subjects from the less-practiced operants vs. the more-practiced alternatives in each operant pair. Results are categorized by both the relative ratio of repetitions prior to testing (grouped into three separate panels left to right, labeled at top) and the absolute value of prior repetitions (along the *x*-axis).

the reader to more easily visualize the keystrokes making up the operant and permit direct comparison between Experiments 1 and 2. Participants in Experiment 2 never saw the letters normally associated with these keys.)

Figure 8 shows the test results for all 27 individual operant pairs learned in Experiment 2, arranged in order of preference for the less-practiced alternative (to compare the percentage values for Experiment 2 directly with those from Experiment 1, see Table 7). As in Experiment 1, the degree of preference for the more-practiced alternative varies widely, and is not correlated with the independent variables of the study. Robust systematic operant bias (defined, as in Experiment 1, as more than 50% of the total operants chosen for performance during testing being drawn from the less-practiced alternative) was again observed for 12 of the less-practiced operants in the 27 choice pairs; data for these appear to the right of the dotted line in Figure 8. Only 7 of these 12 operants, however, were among the 12 operants for which bias was observed in Experiment 1; for the remaining 5 operants, bias was recorded only when the letter cues were absent, although the remaining independent variables of the study were the same. Likewise, for 5 of the 12 operants for which bias was recorded in Experiment 1, bias only occurred when letter cues were present.

The 12 less-practiced operants for which bias was observed in Experiment 2 are shown again in Figure 9, which shows the degree of operant bias measured for these operants in Experiment 2 side by side with that (if any) measured for the same operants

Table 6. Complete individual choice data for Experiment 2.

Participant #	Less-practiced operant	More-practiced operant	Less-practiced operant	More-practiced operant	Less-practiced operant	More-practiced operant
2:3 ratio, low values	TIHMJY 50 reps	MVJGUI 75 reps	MVGJYT 50 reps	JHYIGU 75 reps	KTUGNI 50 reps	NBIGYN 75 reps
5501	23	15	0	37	0	38
5502	0	38	0	37	40	0
5503	39	0	0	38	38	0
5504	8	30	15	24	24	16
5506	0	38	0	40	0	40
5508	0	39	0	40	0	40
Total	70	160	15	216	102	134
Grand total for all 3 operant pairs in this category:					187	510
2:3 ratio, med values	ITKVHM 100 reps	BJMNJU 150 reps	KNVBUI 100 reps	UYJBHM 150 reps	JKGYUJ 100 reps	TKUHIB 150 reps
5501	15	24	0	29	22	15
5502	38	0	0	39	26	6
5503	16	18	40	0	38	0
5504	6	30	23	16	24	15
5506	0	37	0	40	40	0
5508	0	40	23	16	40	0
Total	75	149	86	140	190	36
Grand total for all 3 operant pairs in this category:					351	325
2:3 ratio, high values	BHJMHK 200 reps	GUKYJI 300 reps	HNKGHU 200 reps	YTKBJI 300 reps	TYNVGY 200 reps	MHYUIK 300 reps
5501	8	30	37	0	0	33
5502	23	16	40	0	0	37
5503	16	22	0	34	0	40
5504	23	16	23	15	16	24
5506	24	16	40	0	0	40
5508	24	16	32	7	0	39
Total	118	116	172	56	16	213
Grand total for all 3 operant pairs in this category:					306	385
2:4 ratio, low values	JYTHUK 50 reps	VHMGJK 100 reps	BUIGHK 50 reps	MBKUYJ 100 reps	VGJBYU 50 reps	NGYHVJ 100 reps
5501	0	34	0	31	0	40
5502	38	0	38	0	0	40
5503	31	8	39	0	0	39
5504	7	32	15	20	16	24
5506	40	0	40	0	0	40
5508	16	24	40	0	8	32
Total	132	98	172	51	24	215
Grand total for all 3 operant pairs in this category:					328	364
2:4 ratio, med values	NKUGYM 100 reps	GYJTHU 200 reps	YUKVHJ 100 reps	TMYIBY 200 reps	UIBTYJ 100 reps	JVBMHG 200 reps
5501	0	38	36	0	38	0
5502	0	38	39	0	33	0
5503	0	38	0	39	0	37
5504	0	34	20	16	22	15
5506	0	39	40	0	40	0
5508	0	40	0	39	32	8
Total	0	227	135	94	165	60
Grand total for all 3 operant pairs in this category:					300	381
2:4 ratio, high values	GTMKJT 200 reps	HKTBVU 400 reps	NYTKUH 200 reps	YJIBNM 400 reps	YBHMBU 200 reps	UHBNKY 400 reps
5501	31	8	0	39	0	39
5502	0	40	0	39	0	33
5503	24	10	40	0	38	0
5504	22	15	14	24	16	24
5506	36	0	0	40	0	40
5508	38	0	0	39	40	0
Total	151	73	54	181	94	136

(*Continued*)

Table 6. (Continued).

Participant #	Less-practiced operant	More-practiced operant	Less-practiced operant	More-practiced operant	Less-practiced operant	More-practiced operant
Grand total for all 3 operant pairs in this category:					299	390
2:5 ratio, low values	NYGNIB 50 reps	MUBYNI 125 reps	BYKHNJ 50 reps	VTNGBJ 125 reps	HJIHMN 50 reps	BVKHIY 125 reps
5501	29	7	16	20	24	16
5502	33	0	37	0	0	39
5503	31	0	0	37	0	37
5504	31	0	12	24	21	16
5506	36	0	0	40	40	0
5508	7	32	0	40	40	0
Total	167	39	65	161	125	108
Grand total for all 3 operant pairs in this category:					357	308
2:5 ratio, med values	JMGNKH 100 reps	KJYIGJ 250 reps	UGKJIB 100 reps	KHBNJG 250 reps	IBJTHK 100 reps	GBJMHT 250 reps
5501	4	30	16	24	0	32
5502	0	37	0	39	38	0
5503	8	28	0	39	0	40
5504	14	21	16	24	15	24
5506	32	7	0	39	8	31
5508	39	0	8	32	8	32
Total	97	123	40	197	69	159
Grand total for all 3 operant pairs in this category:					206	479
2:5 ratio, high values	VNKJTI 200 reps	HUBTHI 500 reps	KGNJHT 200 reps	IYGMHV 500 reps	HUMTUI 200 reps	VYNKUB 500 reps
5501	0	40	23	15	0	39
5502	40	0	37	0	0	40
5503	25	15	0	39	38	0
5504	13	24	24	16	24	15
5506	0	40	40	0	40	0
5508	0	40	40	0	32	8
Total	78	159	164	70	134	102
Grand total for all 3 operant pairs in this category:					376	331

in Group A of Experiment 1 (for which the training variables such as order and specific repetitions per operant were identical to those in Experiment 2). The columns are arranged from left to right in order of the difference in bias between Experiment 2 and Experiment 1, showing that all but 3 of these 12 operants were chosen for performance more often in Experiment 2, when the letter cues were absent, than in Experiment 1 under the conditions for Group A.

These results show that the replacement of letters with symbols did not eliminate or reduce operant bias; in fact, although the number of operants for which bias was measured stayed the same (12) in both experiments, the overall level of bias increased in Experiment 2, although it is difficult to determine the exact degree of this increase due to the large amount of variation among individual participants in both studies. Table 7 summarizes the choice data for each operant pair measured in both experiments under all different conditions.

The results from these studies indicate that bias, for this particular operant type, represents an interaction between the effects of the letter cues present only in Experiment 1, and the kinesthetic factors which are present in both experiments. In other words, the physical movements required to press the required keys in the required order (which make up the actual performance of the operant) are not functionally equivalent across the operants used in these studies. This may seem surprising at first,

Table 7. Combined percentage individual operant choice data from Experiments 1 and 2.

Participant groups	Less-practiced operant (%)	More-practiced operant (%)	Less-practiced operant (%)	More-practiced operant (%)	Less-practiced operant (%)	More-practiced operant (%)
	TIHMJY	MVJGUI	MVGJYT	JHYIGU	KTUGNI	NBIGYN
Exp. 1 Group A	16.33	83.67	20.34	79.66	33.00	67.00
Exp. 1 Group B	36.70	63.30	43.15	56.85	0.00	100.00
Total Exp. 1	27.05	72.95	32.60	67.40	15.15	84.85
Experiment 2	30.43	69.57	6.49	93.51	43.22	56.78
	ITKVHM	BJMNJU	KNVBUI	UYJBHM	JKGYUJ	TKUHIB
Exp. 1 Group A	16.50	83.50	49.49	50.51	66.67	33.33
Exp. 1 Group B	14.71	85.29	55.46	44.54	71.30	28.70
Total Exp. 1	15.56	84.44	52.68	47.32	69.16	30.84
Experiment 2	33.48	66.52	38.05	61.95	84.07	15.93
	BHJMHK	GUKYJI	HNKGHU	YTKBJI	TYNVGY	MHYUIK
Exp. 1 Group A	16.72	83.28	50.17	49.83	80.47	19.53
Exp. 1 Group B	0.00	100.00	48.81	51.19	28.53	71.47
Total Exp. 1	7.74	92.26	49.45	50.55	52.48	47.52
Experiment 2	50.43	49.57	75.44	24.56	6.99	93.01
	JYTHUK	VHMGJK	BUIGHK	MBKUYJ	VGJBYU	NGYHVJ
Exp. 1 Group A	47.14	52.86	50.51	49.49	39.01	60.99
Exp. 1 Group B	56.25	43.75	94.22	5.78	85.67	14.33
Total Exp. 1	51.97	48.03	74.18	25.82	64.82	35.18
Experiment 2	57.39	42.61	77.13	22.87	10.04	89.96
	NKUGYM	GYJTHU	YUKVHJ	TMYIBY	UIBTYJ	JVBMHG
Exp. 1 Group A	29.97	70.03	67.53	32.47	0.00	100.00
Exp. 1 Group B	14.41	85.59	100.00	0.00	28.82	71.18
Total Exp. 1	21.58	78.42	84.64	15.36	15.55	84.45
Experiment 2	0.00	100.00	58.95	41.05	73.33	26.67
	GTMKJT	HKTBVU	NYTKUH	YJIBNM	YBHMBU	UHBNKY
Exp. 1 Group A	50.52	49.48	12.93	87.07	16.72	83.28
Exp. 1 Group B	57.89	42.11	26.02	73.98	14.08	85.92
Total Exp. 1	54.53	45.47	19.97	80.03	15.30	84.70
Experiment 2	67.41	32.59	22.98	77.02	40.87	59.13
	NYGNIB	MUBYNI	BYKHNJ	VTNGBJ	HJIHMN	BVKHIY
Exp. 1 Group A	17.25	82.75	56.08	43.92	33.67	66.33
Exp. 1 Group B	42.35	57.65	85.25	14.75	13.83	86.17
Total Exp. 1	30.93	69.07	71.65	28.35	22.98	77.02
Experiment 2	81.07	18.93	28.76	71.24	53.65	46.35
	JMGNKH	KJYIGJ	UGKJIB	KHBNJG	IBJTHK	GBJMHT
Exp. 1 Group A	53.09	46.91	33.56	66.44	13.33	86.67
Exp. 1 Group B	65.58	34.42	39.40	60.60	29.15	70.85
Total Exp. 1	59.97	40.03	36.67	63.33	21.77	78.23
Experiment 2	44.09	55.91	16.88	83.12	30.26	69.74
	VNKJTI	HUBTHI	KGNJHT	IYGMHV	HUMTUI	VYNKUB
Exp. 1 Group A	0.00	100.00	83.22	16.78	66.67	33.33
Exp. 1 Group B	14.66	85.34	53.24	46.76	71.68	28.32
Total Exp. 1	7.82	92.18	67.24	32.76	69.38	30.63
Experiment 2	32.91	67.09	70.09	29.91	56.78	43.22

considering the very small motions involved—the window cut in the particleboard keyboard mask to allow access to the 12 letter keys used (plus the space bar) is only about 3 inches square, and most people are capable of typing within this small space using mostly movements of the fingers, while moving the hand only occasionally. But given the results, some of these small motions were, in fact, favored over others by our participants, creating a source of operant bias.

We assume, for the purposes of our analysis, that the symbols which replaced the letters as visual cues, though they are certainly not completely association-free, did not

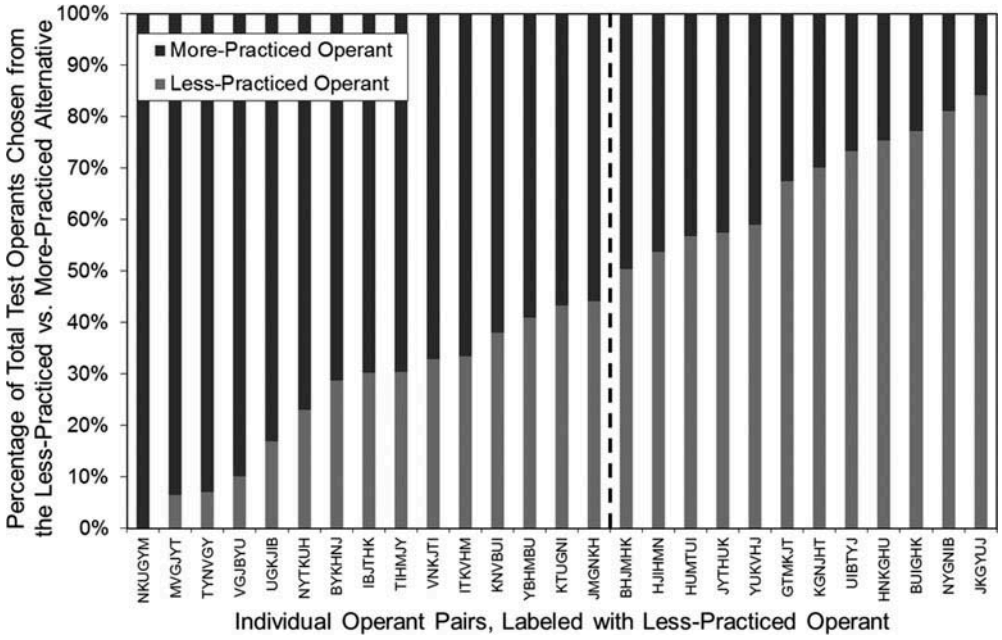

Figure 8. Choice results during testing for individual operant pairs in Experiment 2, arranged in order of least to most preference for the less-practiced operant in the pair. The 12 operant pairs to the right of the dotted line are those for which more than 50% of the total operants performed during testing were from the less-practiced alternative, thus demonstrating bias for those operants.

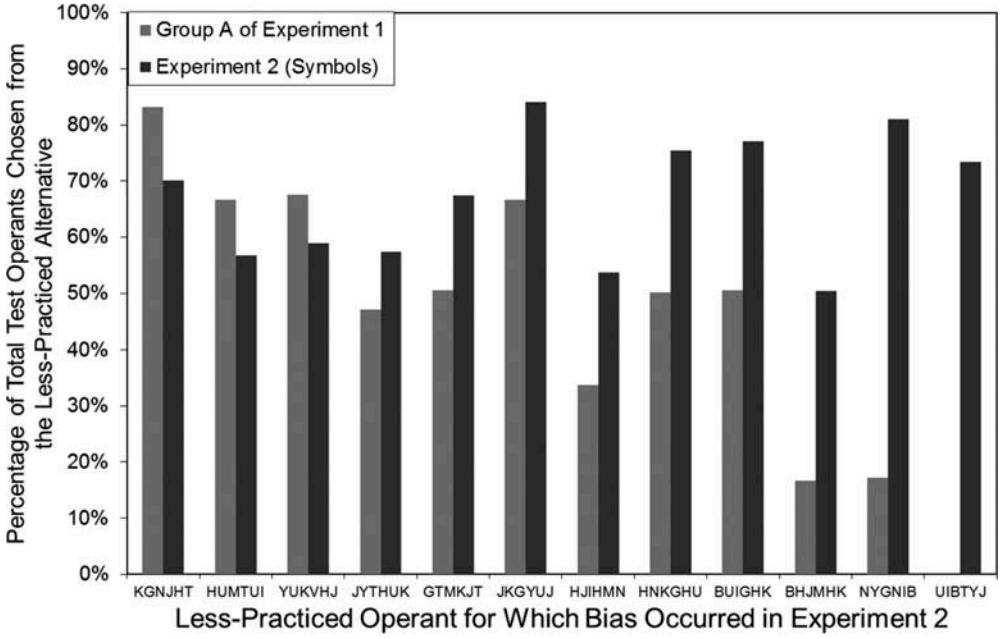

Figure 9. Degree of operant bias measured for the 12 less-practiced operants in Experiment 2 that were chosen more than 50% of the time during testing, shown side by side with the equivalent degree of preference measured in Experiment 1 for participants in Group A (for whom the experimental conditions were equivalent to those in Experiment 2). The results are arranged in order of amount of difference between the experiments.

introduce a new source of bias larger than the one which was removed. Letters of the alphabet have complex multisensory verbal associations for speakers of English which symbols simply do not (they evoke the participant's history with the sounds associated with those letters in speech, as well as their use in typing and handwriting). The alphabetic prompts thus appear to modulate the effects of the consistent kinesthetic influence, increasing bias for some operants and decreasing it for others.

Given this strong kinesthetic basis for the bias observed, analysis for Experiment 2 then was redirected from the numeric choice data already presented to focus on the kinesthetic aspects of the operants themselves. In what way are the movements required to perform the 12 biased operants quantitatively different from the movements required for their 12 more-practiced alternatives? And how do those differences compare to those between operants in the other 15 choice pairs, for which bias was not observed? Three intriguing results were found in this alternate analysis of Experiment 2.

First of all, if one simply counts how many of the six keys that make up each operant are from each of the three rows on the keyboard (the bottom row, the middle row and the top row), it is evident that the biased operants contain far more keystrokes from the middle row of the keyboard than their alternative operant choices, and far fewer keystrokes from the bottom row. Figure 10 shows this visually, with the solid color columns representing biased operants vs. their more-practiced alternatives, and the striped columns representing the

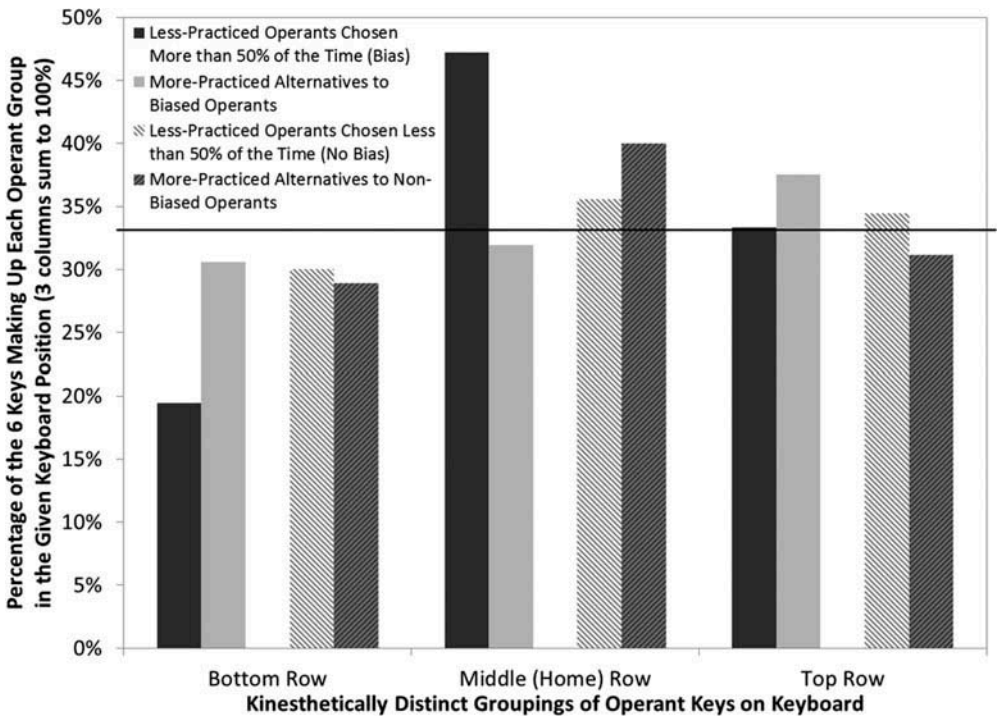

Figure 10. Kinesthetic operant bias, related to the position on the keyboard of the individual letter keys making up each operant when the letter cues themselves are absent. Biased and non-biased operant groups in Experiment 2 are shown categorized by the percentage of their total keystrokes from each row of the keyboard.

operant pairs for which bias did not occur. The number of keys from the top row is about equal between all groups, and in general the striped columns (no bias) are much closer together, and closer to the "average" level of 33.33% (the value which all columns would have if the keystrokes had been equally drawn from all three rows). The middle row of the keyboard is the one commonly known as the "home" row, the one on which one is taught to rest one's hands when learning how to touch type (which then has the secondary effect of blocking the keys on the bottom row from view). This aspect of the operant, then, is related to a long history of motor learning and behavior for almost all adult participants.

Secondly, when typing the six keystrokes of each operant in sequence, five unique small movements are required, one from each letter key to the one that follows it. These motions fall into two clear categories: movements between keys which are immediately adjacent to each other, and movements between keys which are not, requiring a larger motion or "shift," sometimes of the whole hand rather than just the fingers. If one counts how many of the movements making up each operant fall into each category, one sees that biased operants contain far fewer of these "shifts" between non-adjacent keys than their more-practiced alternative choices. Figure 11 shows this result.

Almost 50% of the keys in the biased operants are immediately adjacent to the previous key, vs. less than 20% for the more-practiced group. The difference between less- and more-practiced operants in pairs for which bias was not observed is in the

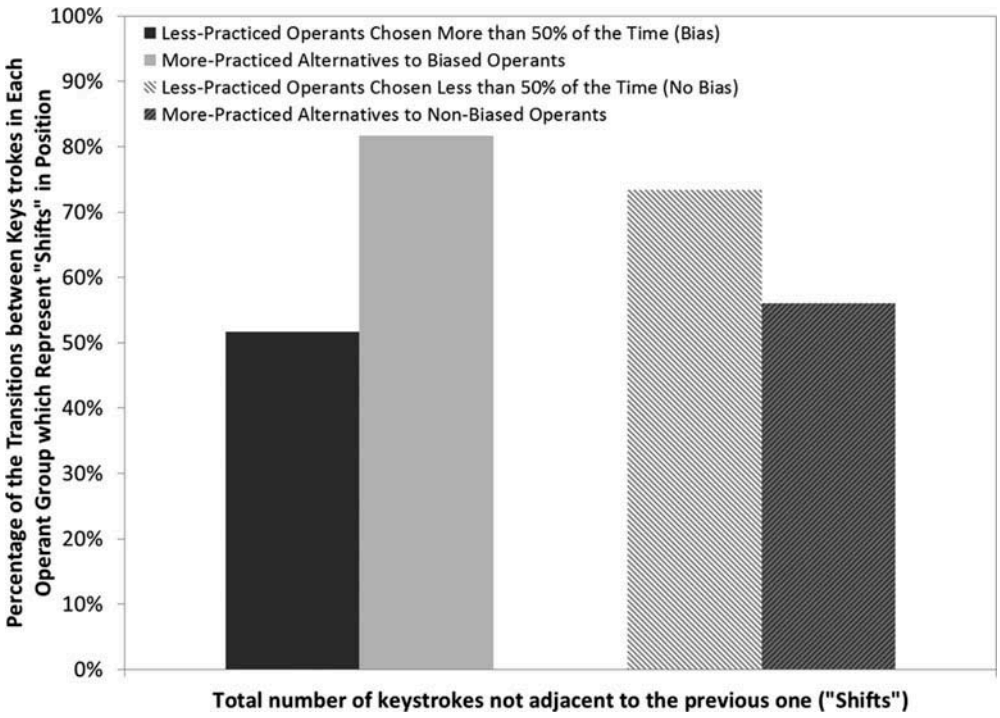

Figure 11. Kinesthetic operant bias when letter cues are absent, related to the effort required to emit each operant. Biased and non-biased operant groups in Experiment 2 are shown categorized by the percentage of the total movements between keystrokes which require a longer "shift" to a non-adjacent key.

opposite direction, and less pronounced. Operant bias is thus linked to ergonomic efficiency of motion: biased operants simply require less effort to type.

Finally, looking at the angle of motion required for all five unique movements between keystrokes in each operant (as opposed to the distance required for those five movements, as in the last analysis) reveals that biased operants contain more direct left-to-right movements and movements away from the participant's own body, and less direct right-to-left movements and movements toward the participant's body, than do the more-practiced alternatives, or the operant pairs for which no bias was observed. This distinction is most pronounced when looking just at the initial unique angle of motion required for each operant (between the first and second "letter" keystroke, as the movement from the space bar to the first keystroke is naturally in the same direction for all operants). This result is shown in Figure 12. Again, the difference between less- and more-practiced operants for which bias was not observed is far smaller, almost evenly split between the two categories of motion. These three kinesthetic factors together make up a large portion of the overall physical experience of performing the operants in these experiments; they do not develop during the course of learning (based on kinesthetic feedback from each immediately previous response), but instead are related to the biological aspects of the participants' typing behavior, as well as their lifetime learning histories with the computer keyboard.

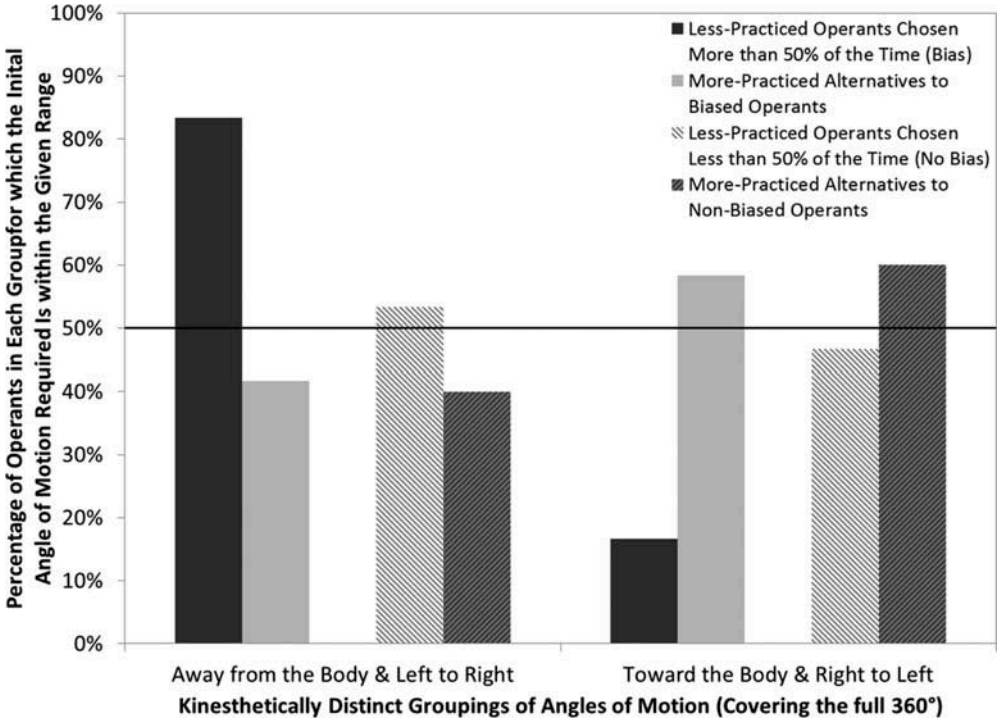

Figure 12. Kinesthetic operant bias when letter cues are absent, related to the angle of the initial hand movement required. Biased and non-biased operant groups in Experiment 2 are shown categorized by the direction in relation to the participant's own body of the initial movement required to type the sequence.

Discussion

These basic differences in kinesthetic factors found for biased operants in Experiment 2 are in line with similar biases found in our previous studies and others. Regarding the bias for keys from the "home" row of the keyboard, the particleboard mask covering most of the keyboard during these experiments was originally designed to prevent the participants from drawing on any well-established behavioral repertoire of touch-typing they may have had, but this design feature did not have the desired effect. Placing the mask's window in the middle of the keyboard physically prevented participants from hovering both hands over the usual left- and right-side "home keys" taught in touch-typing (ASDF and JKL plus the ";" key), but, as all three rows of the keyboard were still available, it did nothing to prevent them from placing their hand over the middle row.

This bias toward the middle row of the keyboard (and away from the bottom one) turns out to be confirmed by numerous ergonomic studies of typing, dating back a 100 years to Frank and Lillian Gilbreth's famous "time-and-motion" efficiency studies of skilled behavior, in which they filmed industrial workers, including typists, performing their jobs and then slowed the film down in order to time the movements with precision (Gilbreth & Gilbreth, 1920). Typing is simply fastest on the home row and slowest on the bottom row, with typing speed on the top row falling in between those two extremes.

The finding that biased operants contain far fewer "shifts" to non-adjacent keys is also strongly supported by ergonomic studies of typing behavior, which show that the largest determining factor in the efficiency of typing is what is known as key-to-key travel distances. The Dvorak keyboard, designed as a more-efficient alternative to the standard QWERTY keyboard, has a very large advantage in common key-to-key distances over its rival, leading to a reported superiority in speed when typing on the Dvorak keyboard of anywhere from 2.5% to 11% (see Ober, 1992, for a review of the ergonomic experiments carried out on the Dvorak keyboard).

Finally, the bias for operants in which the initial angle of motion is away from the body or from left to right matches our own recent study of operant bias recorded in experiments using a different type of operant (drawing lines on a computer graphics tablet). We observed that participants overwhelmingly preferred to draw either from left to right, or in a direction away from their own torso (Jones & Mechner, 2013). They were systematically less likely to choose operants which required drawing from right to left, or in a direction toward themselves. These preferences were most pronounced when looking at the initial movement required to perform an operant. The movements making up the current keyboard-based operant behavior, although much smaller, appear to be subject to a similar kinesthetic bias.

General discussion

In the experimental analysis of behavior, operant bias is normally thought of as a potential methodological problem which the experimenter attempts to solve by controlling for it, or cancelling it out by arranging the different values of the experiment's independent variables. But bias, both stimulus bias and operant bias, is not just random variation but systematic behavior, and like all behavior, can be studied directly. A

possible future direction for bias research is whether, and if so how, bias also occurs in covert behavior, and in behavior that occurs only at the level of thinking.

The two experiments described in this article, like those explored in our previous article on bias (Jones & Mechner, 2013), present evidence of clear and systematic operant bias which at first appeared random and inexplicable. But when analyzed rigorously and quantitatively, these biases can be understood not only on a behavioral level, but also on a biological one. The human body has many coordinative structures for movement, which link different muscles (such as those of the hand) together both mechanically (through the joints and tendons) and at the neural level, so that complex motor programs can be carried out more efficiently, or at all (Bernstein, 1967; see Normand, LaGasse, Rouillard, & Tremblay, 1982 for an example of one such coordinative structure). Such linkages should be taken into account when designing operant behavior experiments so as to minimize the potential for kinesthetic operant bias. Furthermore, as we discovered when analyzing the data from the experiments designed in this article, a search of applicable research outside of the experimental psychology literature can often be helpful in understanding bias.

The kinesthetic basis of the observed biases, and the fact that they match results from the field of ergonomics and efficiency research, suggests that they would be broadly applicable to any type of typing behavior which is required to be both fast and accurate. These findings may also have implications not only for research involving human performance on a computer keyboard (see Kroemer, 2001, for a comprehensive bibliography of 120 years of research on the design and use of keyboards), but for any performance requiring complex responses that involve coordinated muscle groups, particularly of the hands.

Disclosure statement

No potential conflict of interest was reported by the authors.

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